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How do new ventures successfully create an ecosystem to capture value from a disruptive technology?

by

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List of Abbreviations

3D Printer	Three-Dimensional Printer
3DCP	Three-Dimensional Concrete Printing
3DP	Three-Dimensional Printing
AM	Additive Manufacturing
BIM	Building Information Modelling
BoP	Base of the Pyramid
CABS	Chartered Association of Business Schools
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
DfMA	Design for Manufacturing and Assembly
GVC	Global Value Chain
MDM	Material Deposition Method
MMC	Modern Methods of Construction
NGO	Non-Government Organisation
PPVC	Prefabricated Prefinished Volumetric Construction
RBV	Resource Based View
RDT	Resource Dependence Theory
SLR	Systematic Literature Review
SM	Subtractive Manufacturing
STL	Standard Tessellation Language
TCE	Transactional Cost Economics
WoS	Web of Science

Acknowledgements

‘The dwarf sees farther than the giant, when he has the giant's shoulder to mount on’
Samuel Taylor Coleridge, The Friend (1818)

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I dedicate this thesis to my wife Sally and my son Henry

Declaration of Originality

I declare that this thesis '*How do new ventures successfully create an ecosystem to capture value from a disruptive technology?*' is my own work and no part of the dissertation has been previously submitted to any other university for any degree, diploma or other qualification. Previously submitted work by the author in the form of a reviews and conference presentations are drawn on for parts of this thesis. When reference is made to the work of others, the extent to which it has been used is indicated in the text and bibliography. Any errors or omissions within this thesis are the sole responsibility of the author.

This document contains 82,193 words, excluding bibliography and appendices, and therefore adheres to the requirements of Warwick Business School, University of Warwick.

Signature:

Name of Student: *Robert James Brennan*

Name of Supervisors: *Professor Deniz Ucbasaran*
Professor Duncan Shand

Copyright

Research Question

How do new ventures successfully create an ecosystem to capture value from a disruptive technology?

Abstract

Can the construction industry adopt new technologies to solve the wicked problem of acute housing shortages across the globe? Is the introduction of 3D Construction Printing (3DCP) and the digitalisation of the house building process a viable solution and will it be successfully deployed?

This thesis explores how new ventures are creating ecosystems to capture value from a disruptive technology and examines the requirements to be successful in this area. Whilst researching the fields of business ecosystems and disruptive innovation, in the context of the construction sector, the findings point to how business model innovation may be an additional driver for the adoption of new technology in a highly regulated, traditional industry rather than technology innovation. The research highlights the potential for modern methods of construction and new business platforms in this sector and proposes practical steps for these to be successful.

A qualitative case study research approach was undertaken to add a practical contribution to the literature on strategies employed to utilise nascent technologies.

The findings suggest that the success of a disruptive technology depends on the emergent business ecosystem, the identified actors in that ecosystem and the intentions of those actors for that technology to become established.

The outcome is a practical toolkit for new companies in the construction industry deploying the latest innovative technologies and business strategies.

1 Introduction

This chapter presents the background, aims and objectives of this research. It introduces the theories employed and provides a synopsis of the contribution. It also outlines the structure of the thesis.

1.1 Research Background - Practical Problems

1.1.1 The World's Housing Shortage: A Wicked Problem

The World has seen a staggering rise in human population over the past 300 years (See Figure 1.1 below). Within my lifetime the World's population is projected to triple from 3.4 billion people in 1966 to an estimated 9.8 billion by 2050 (United Nations, 2017). Of the additional 2.2 billion people estimated from 2020 to 2050, 1.3 billion will be in Africa, with Asia estimated as the second largest contributor, growing by 750 million people over the same time period. These areas represent some of the poorest regions of the world, with many existing inhabitants at the 'Base of the Pyramid' (BoP) earning less than $8 per day (Prahalad & Hart, 2002). This unprecedented acceleration in the expansion of humankind will have huge social, economic and environmental consequences unless practical measures are taken to provide sustainable methods to house, feed, educate and employ people.

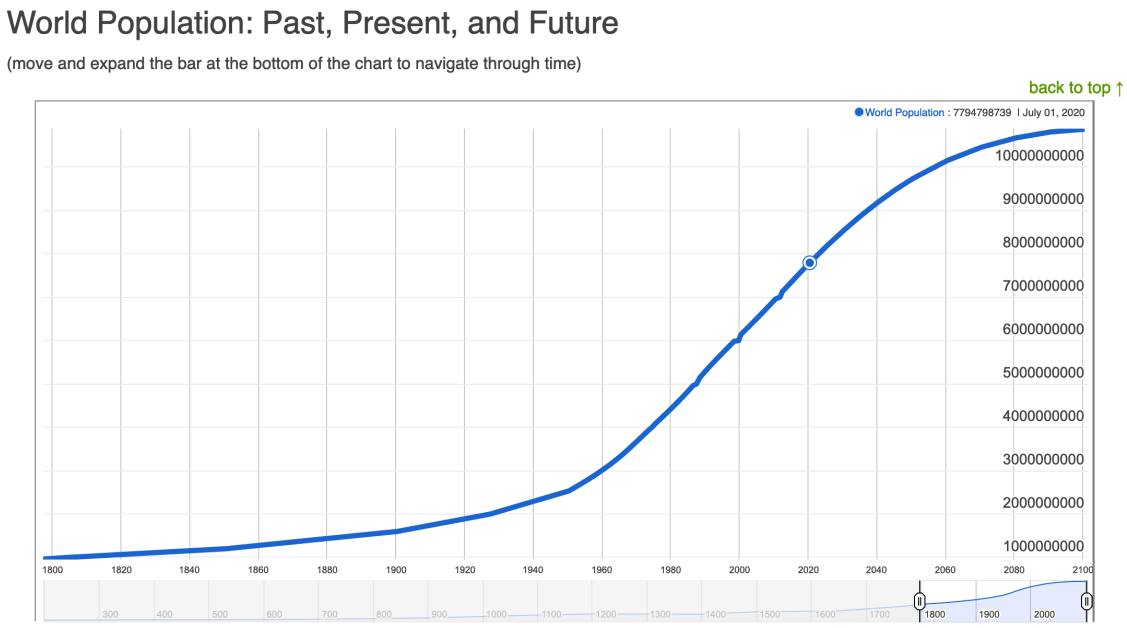


Figure 1.1 World Population (www.worldometers.info/world-population)

Separately The World Bank (2016) estimates that by 2030, 40% of the world's existing population, representing 3 billion people, will need new homes with the majority of the requirement coming from the developing markets. Consequently the World Economic

Forum considers housing as one of the megatrends facing the world with 200,000 people per day moving to urban areas (WEF, 2016). This migration includes an estimated 40,000 people moving from rural areas to cities across Africa each day (IFC, 2015). As a typical example of the expected demand, one of the largest forecasted requirements is in Nigeria, where a growing population is expected to double from 200 million to 400 million by 2050 resulting in a housing demand for an additional 17 million units (The Economist, 2015). To budget for this, recent data from the Federal Ministry of Lands, Housing and Urban Development has revealed that Nigeria will require an estimated N59.5 trillion (US$85 billion) to bridge its housing gap, through the construction of two million housing units each year over the next 10 years (Leadership, 2019).

Therefore, nations across the world faced with expanding populations, especially those in Africa and Asia, will need to embrace the new technologies and innovations in digital construction to provide high quality yet affordable homes or risk major social unrest.

However, it is not just developing countries that need housing with a recent report that suggests the UK requires 3.1 million homes to solve its own social housing shortage, costing up to £10.7 billion per year during the construction phase (Shelter, 2019). To hit this target 150,000 houses per annum are required for the next 20 years, yet the average number built for social housing has only averaged 20,000 over the past two decades (Crosby, 2019).

Modern methods of construction (MMC) must be harnessed to allow a step change reduction of construction costs, more efficient use of resources, replicable high quality, rapid construction and unlimited designs.

1.1.2 Construction Industry: A Productivity Problem

At a time when the rapid urbanisation across the globe requires a bold solution in order to avoid a housing crisis and the resultant social unrest, a lack of productivity gains hinders the construction sector. The global construction sector accounts for nearly $10 trillion per annum in construction related goods and services, representing 13% of the World's GDP (MGI, 2017). Yet whilst productivity in manufacturing, retail, and agriculture has grown substantially, productivity in the construction sector has barely increased at all. For a sector that employs approximately 7% of the world's population, construction continues to significantly lag other sectors in adopting best practice (Figure 1.2 below).

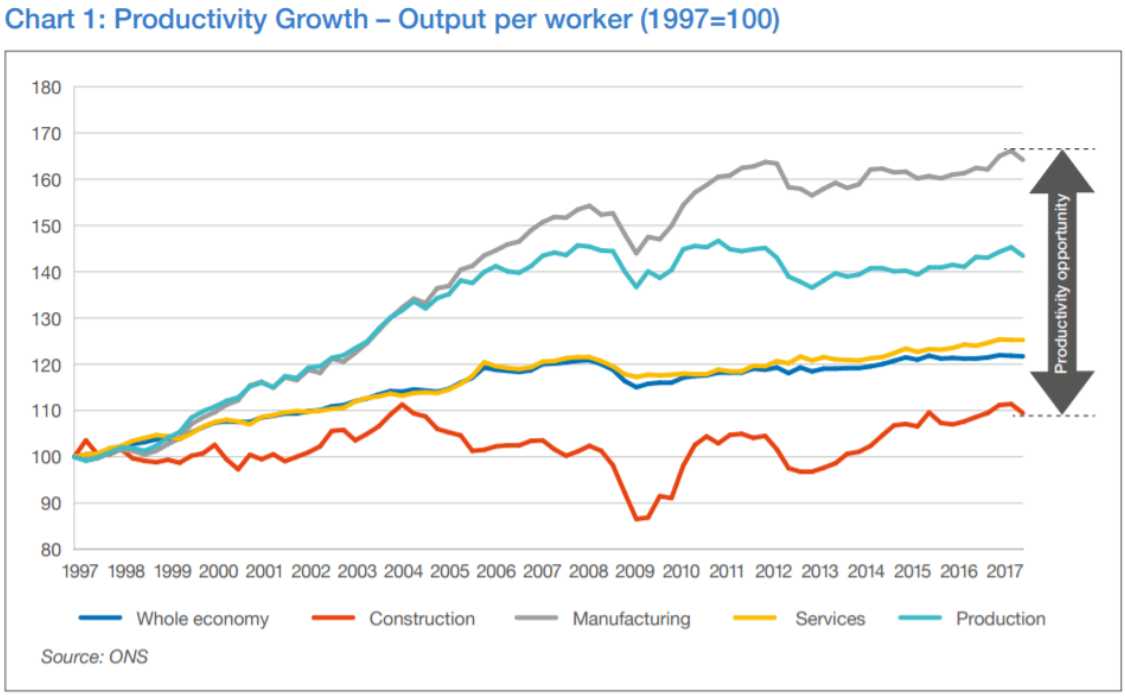


Figure 1.2 Industry Sector Productivity (IPA, 2017:13, Chart 1)

Farmer (2016:06) reported that the construction industry stands at a crucial juncture and needs to address deep rooted problems. Using a medical analogy, he stated that "*many of the features of the (construction) industry are synonymous with a sick, or even a dying patient*" with symptoms including low productivity, low predictability, structural fragmentation, low margins and a lack of R&D and investment in innovation as well as a poor image.

If lean processes involving mass production of standardised parts can be utilised in the construction sector, a five- to ten-fold estimated increase in labour productivity could lead to cost savings of up to $1.6 trillion per year (MGI, 2017:08).

1.1.3 Incumbents vs Innovators: A Disruption Problem

It is not only objectively more difficult to do something new than what is familiar and tested by experience, …The history of science is one great confirmation of the fact that we find it exceedingly difficult to adopt a new scientific point of view or method (Schumpeter, 1934:2366).

Many incumbent construction companies are focused on traditional methods of building houses and appear hesitant to adopt new methodologies unless their current business is threatened. This is a classic example of an industry ripe for disruption, especially if the innovators goal is to benefit the wider community and those under-served by incumbent house builders, as theorised by Christensen in his seminal book *The Innovators Dilemma* (Christensen, 1997).

Whilst seemingly identical, most houses are actually a bespoke product made to order, rather than assembled along lean process techniques typically employed in other industries, such as manufacturing or car production. However, whilst the incumbent construction firms continue to focus on cost, other players in their ecosystems include nascent technology companies determined to utilise these modern methods to realise a better product for the next generation of consumers. Disruptive innovation will affect the incumbents and they will need to adjust their strategies to face the forthcoming challenges to their business models as entrepreneurs and innovators disrupt sectors to enhance the social benefit of products and lift nations out of poverty through innovation (Christensen *et al.*, 2019).

This increasing demand for quick build, low cost, high quality residential houses presents new opportunities for innovators whilst potentially alleviating the social problems faced by the approximate 4 billion people currently living at the base of the pyramid (Prahalad & Hart, 2002). With an estimated housing market in the 36 low- and middle-income countries for which standardized data exist is $187.5 billion (Hammond *et al.*, 2007) this represents an attractive market opportunity for new ventures to create value through addressing a neglected problem involving neglected positive externalities (Santos, 2012). Therefore, modern methods of construction can address the massive social demand for cost effective, sustainable, safe homes in the developing countries of the world by utilising the techniques of commercial entrepreneurs to construct markets in nascent technologies (Santos & Eisenhardt, 2009). This technological innovation will disrupt the existing construction industry.

Separately, there are also opportunities for innovation in financing models and business processes that can cut costs and raise efficiencies for the industry and the consumer. Disruptive innovations will alter existing supply chains and business models through the emergence of manufacturing titans (D'Aveni, 2018). Construction industry incumbents must consider how all these innovations will affect their whole business strategy or risk displacement by innovators.

1.1.4 External Strategy: A Business Ecosystem Problem

New companies often have a great innovation or idea that they want to bring to market. The construction industry is undergoing a trend towards automation and digitalisation which is attracting new types of companies with skillsets not usually associated with this industry. Companies involved in robotics, automation, artificial intelligence (AI), virtual and augmented reality (VR/AR) and cloud technologies are starting to invest time and resources to provide products and services to enable a more efficient and

cost-effective building process. The question is how these small start-ups and innovative enterprises build a business ecosystem to bring their product into the marketplace and capture value from it. Business ecosystems are now appearing where companies co-create and market a new innovative product (Moore, 1993; Moore, 1996) with either a keystone player (Iansiti & Levien, 2004a) as the driving force or a collection of firms collaborating with a shared value proposition (Adner, 2017). The construction technology innovations could represent a game changer in how residential houses are built in the near future providing that firms can find the right balance between co-operation and competition within their ecosystem strategy (Adner, 2006; Adner *et al.*, 2013). This research considers how the new ventures in construction are developing their ecosystems and what bottlenecks and obstacles are they encountering.

1.1.5 Internal Strategy: A Business Model Problem

Technology will dramatically affect way the world conducts business. Supply chains will be shortened, firms will move from '*economies of scale'* to '*economies of scope'* and new business platforms and ecosystems will emerge to command the altered business landscape (D'Aveni, 2018). Complementary to the emergence of ecosystems, these new ventures look to capture value from disruption using the business model as the source of value creation and innovation (Amit & Zott, 2012).

The nature of business model choices has consequences as it can influence the ecosystem's behaviour (Sanchez & Ricart, 2010). In *isolated* business models, interdependences within the ecosystem are negative as firms compete, whereas in *interactive* business models, interdependences are more numerous (with more fringe actors in the ecosystem) and positive where firms cooperate. Whilst the ecosystem sees incremental improvement under isolated business models, interactive business models generate value as new actors join. "*Creating an ecosystem that co-evolves with inputs from global and local partners, many of them located outside the formal economy, not only helps to improve socio-economic context, but also allows value creation and it is a source of a more sustainable competitive advantage than in the case of isolated business models"* (Sanchez & Ricart, 2010:150). Therefore, new ventures and incumbents need to consider their business model innovation as a source of value alongside their internal dynamic capabilities. In effect both the technology and the business model will be important to capture value (Teece, 2010; 2018a).

1.2 The Research Question

A DBA is the practical application of existing academic theories to a business problem. Therefore, after various iterations, my research question settled on **"How do new ventures successfully create an ecosystem to capture value from a disruptive technology?**

This study uses the latest research in the fields of Disruptive Innovation and Business Ecosystems to provide a practical toolkit to enable new ventures to capture value from a nascent technology. This qualitative case research study focuses on the innovations to digitalise construction as viewed through the eyes of incumbents and disruptors. It is aimed at academics and practitioners interested in ecosystems, disruptive innovation and business model innovation It is also of use to small new ventures looking to use their innovations to break into traditional markets where barriers to entry may seem high.

1.3 Research Gap

The recent advances in technology, including data capture and analysis as well as process automation, point to potentially revolutionary new approaches to construction (D'Aveni, 2018). New business models employing *economies of scope,* where multi-product 3D printers can be used to replace single process machines will result in new business platforms and manufacturing titans (D'Aveni, 2018). Separately, incumbents are being forced by government regulation and initiatives to adopt better manufacturing and procurement processes (IPA, 2017). Consequently, business processes and supply chains are being reconfigured to take advantage of these new technologies (WEF, 2017).

However, the existing body of knowledge in business ecosystems and disruptive innovation has not focused on the construction industry. Where research has been done it is generally in the context of operational management or technical improvement rather than the area of business approach. Secondly, whilst there are many construction industry consultants, the academic research papers in these business research fields are limited. Thirdly, the existing literature has only a small number of articles focused on the start-up phase of a business, employing a disruptive technology or innovation, in consideration of the surrounding business ecosystem. Fourthly, business model innovation also needs to be considered when discussing break out technologies. Finally, whilst 3D printing has seen an exponential number of articles published recently, very little research has been conducted on how 3DCP technology will become established as the construction industry is digitalised.

By observing and interviewing new ventures as well as incumbents, I hope to understand how they are incorporating new technologies into an industry that is viewed as traditional, slow moving, litigious, costly and labour intense and what steps they take to build their ecosystem adding to the existing knowledge in the fields of Business Ecosystems and Disruptive Innovation. An interrelated field is Business Model Innovation, as the chosen model may be the source of value creation for the firm and other actors in the ecosystem (Zott & Amit, 2013).

1.4 Innovation in Construction

The context of this research is focused on innovation in the construction industry, specifically the use of both innovative technology (3D Construction Printing - 3DCP) and process innovation (Digital Twins or Building Information Modelling - BIM).

Other industries such as medical devices, automotive and aerospace have adopted advanced 3D design, scanning and printing techniques to disrupt their status quo. Similar disruptive innovations are now starting to impact the construction sector with small new ventures developing new equipment and building techniques to improve the current state of the industry. This implies a disruption in the construction industry when 3D printing replaces labour-intensive manufacturing processes (Laplume *et al.*, 2016) because Gartner identified 3D printing as "*a rare example of a single technology that has become truly disruptive by itself*" (Prentice, 2014:02).

The degree of disruption depends on the extent to which the new technology changes the affordability of the products produced, which affects consumption, and to what extent the new technology entails a change in the required inputs (Tushman & Anderson, 1986). 3DP technology creates 'whole' products with few intermediate goods resulting in shorter global value chains from raw material extraction, processing and distribution straight to 3DP manufacturing of finished goods (Kothman & Faber, 2016). Gartner has listed 3DP as one of the ten trends to watch since 2015 (Cearley & Walker, 2015). See Figure 1.3 below:

Figure 1.3 Top 10 Strategic Technology Trends (Gartner 2015)

BIM represents the move to digitalising construction with data being the key innovation to reduce labour intensive activities and create a virtual or digital twin for a physical building. The updated report on strategic trends for 2019 from Gartner (Cearley & Burke, 2019), has introduced the use of 'Digital Twins' as digital representations of processes and methods to provide a real-time view of company processes and assets impacting organisational architecture alongside technology innovation.

But are these disruptive technologies that will favour the innovators or just an evolution where the incumbents will have time to build barriers against disruptors and use the innovations themselves?

1.5 Qualitative Method

As 3DCP and BIM are relatively new innovations within the construction industry a quantitative study is not appropriate due to the lack of long-term data, especially on 3DCP companies, so a qualitative case study method has been used. The research consists of over 40 hours of transcribed interviews and presentations accrued between December 2018 – December 2019. Triangulation with website data and industry conference material provided a more robust analysis (Yin, 2018). Interviews were held with both incumbents and disruptors in the emerging areas of 3DCP and BIM. Other potential ecosystem players such as government officials, financiers, research universities and consultants, who are interested in this industry were also interviewed to provide a wider context and to see if there are commonalities in views. I travelled across the UK, Europe and Africa to interview participants in order to further understand the global nature of the housing shortage challenge and potential solutions. A single company unit of analysis was not appropriate considering the lack of a clear

keystone leader in 3DCP and BIM at this stage of development of these innovations. Instead using case research study methodology of a single case study with multiple embedded units of analysis, as described by Yin (2018), allows for rigorous research to be carried out.

Therefore, the single case study is the ecosystem surrounding innovation in construction with the multiple units of analysis as the companies and ecosystem players in that field. All ecosystem actors have been carefully selected to provide a thorough range of views and interests in order to try and provide a practical toolkit that is applicable in multiple situations.

All transcripts were coded in NVivo using a multi-stage process. An initial lumping coding approach followed by a more detailed axial coding method. The resultant 6 themes were then cross referenced against the existing literature. The existing literature was chosen through a systematic literature review focused on ecosystems and disruptive innovation. 86 articles were selected as the most appropriate and these were also coded in NVivo. Themes were matched against the transcripts and data analysed with results shown in the Findings Chapter. From these findings, a practical toolkit has been developed to help companies address the highlighted issues that can be used by new ventures utilising disruptive technologies or innovations in existing business sectors. Six areas typically encountered have been considered and practical methods described to tackle them.

1.6 Practical Toolkit

The outcome of this research is a practical toolkit that emerged from the observations and interviews with the participants. It comprises an overall ecosystem strategy based on an adaptation of the three core components of enterprise strategy (Freeman, 1984), namely an analysis of: 1. *Societal Issues*; 2. *Value Proposition*; 3. *Ecosystem Actors*. The analysis results in six specific toolkit steps that enable companies to successfully deploy an innovation: 1 *Understand your Environment*, 2. *Understand your Innovation*, 3. *Understand the Market Opportunity*, 4. *Get Noticed,* 5. *Develop Internal Capabilities*, 6. *Develop External Capabilities*. These six steps outlined in the Outcomes chapter are an important framework for new ventures to follow when devising a strategy to reach their full market potential. This toolkit acts as a guide through the different stages of ecosystem development and company growth whilst allowing a focus on the important considerations relating to the specific type of innovation in a particular industry setting.

1.7 Key Terms & Definitions

Since several key terms that are repeated throughout this thesis, a list of key terms and definitions are outlined in Table 1.1 to aid the reader.

Table 1.1 Key Terms & Definitions

Key Term	**Definition**
3D Printing	An advanced manufacturing process that can produce complex shape geometries automatically from a 3D CAD model without any tooling, dies and fixtures
3D Construction Printing (Additive Construction)	The process of joining materials to create constructions from 3D model data (Labonnote *et al.*, 2016:348).
Additive Manufacturing	The process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies
Base of the Pyramid	Reference to the 4 billion people with an income of less than $1,500 per annum, at the base of the wealth pyramid (Prahalad & Hart, 2002)
Building Information Modelling (BIM)	Building Information Modelling (BIM) is defined as *"the use of ICT technologies to streamline the building lifecycle processes to provide a safer and more productive environment for its occupants, and to assert the least possible environmental impact from its existence, and to be more operationally efficient for its owners throughout the building lifecycle."* (Arayici & Aouad, 2010:101)
Business Ecosystem	An economic community supported by a foundation of interacting organizations and individuals—the organisms of the business world. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies. Those companies holding leadership roles may change over time, but the function of ecosystem leader is valued by

	the community because it enables members to move toward shared visions to align their investments, and to find mutually supportive roles (Moore, 1996)
Disruptive Innovation Theory	Christensen defines a disruptive innovation as a product or service designed for a new set of customers. Generally, disruptive innovations are technologically straightforward, consisting of off-the-shelf components put together in a product architecture that was often simpler than prior approaches. They offered less of what customers in established markets wanted and so could rarely be initially employed there. They offered a different package of attributes valued only in emerging markets remote from and unimportant to the mainstream (Christensen, 1997)
Resource Dependence Theory (RDT)	Resource Dependence Theory is the study of how the external resources of organisations affect their behaviour. Organisations depend on resources. These resources originate from an organisation's environment, which also contains other organisations. The resources one organisation needs are often in the hand of other organisations so resources can be a basis of power implying organisations therefore depend on each other. So power and resource dependence are directly linked (Hillman *et al.*, 2009)
Social Network Theory	Network research focuses on either intra-organisational or inter-organisational ties in terms of formal or informal relationships. In larger organisations network research is often conducted at a workgroup level and organisation level, focusing on the interplay between the two structures (Burt, 1992)
Stakeholder Theory	Stakeholder theory argues that there are other parties involved, including employees, customers, suppliers, financiers, communities, governmental bodies, political groups, trade associations, and trade unions. Even competitors are sometimes counted as stakeholders – their status being derived from their capacity to affect

	the firm and its stakeholders (Freeman, 1984)
Strategic Alliances	Strategic alliances are about accessing resources that a particular firm does not already possess, yet which are critical for improving its competitive position (Das & Teng, 1998)
Subtractive Manufacturing	The process where material is machined away from a block to form the desired part; or forming, shaping or casting material in a mould
Value Network	The context within which a firm identifies and responds to customers' needs, solves problems, procures input, reacts to competitors, and strives for profit
Web of Science (WoS)	Research Publications database https://clarivate.com/products/web-of-science/

This introduction has presented the practical problems facing the world's construction companies and identified a research gap to be explored in greater depth using the outlined methods. Two types of innovation currently emerging in the construction industry, 3DCP and BIM, provide a suitable context to explore the business issues and develop potential solutions to these problems.

1.8 Structure of Thesis

This thesis is broken down into separate chapters with a summary of each chapter and its intention is given below in Table 1.2. As this is a DBA, the aim is to evaluate existing knowledge and then formulate a solution that addresses specific business challenges.

This research investigates the specific problem of the global housing shortage and highlights the efforts of innovators in the construction industry chasing business opportunities to automate and digitalise house building and thereby add value to existing firms as well as newcomers to this industry.

I have focused on purposively selected companies which were observed with referral back to the current and emerging literature on Disruptive Innovation (Christensen *et al.*, 2019; D'Aveni, 2018) and Ecosystems (Adner, 2017; Jacobides *et al.*, 2018) before I propose a toolkit that could potentially be utilised by innovative construction companies.

Table 1.2 Overview of Thesis Structure by Chapter

Chapter	**Overview**
1. Introduction	The introduction provides the background context to this research. The aim is to identify practical issues seen in the business world, and devise solutions to address them. The problem and the scope of the research study have been highlighted, the research gap and research question identified, the setting and methods employed stated and the toolkit solution outlined.
2. Case Study	This research is a single case embedded with multiple units of analysis. The case is focused on the ecosystem surrounding innovation in the construction industry whilst the multiple units of analysis are the companies identified as disruptive innovators, incumbent firms and the wider ecosystem actors. This research focuses on two innovations: 3D Construction Printing (3DCP) and Building Information Modelling (BIM). A brief introduction for both innovations is presented to provide the reader with context.
3. Literature Review	A systematic literature review was undertaken for a critical review of the extant literature in the fields for ecosystems, disruptive innovation and 3D printing. The fields of resource dependence theory, stakeholder theory and networks were also considered to provide antecedent and contemporary areas of literature research.
4. Methods	The methods section is a descriptive chapter of the methods employed and the reasons for choosing them. It contains an outline of the research setting, the selection of cases, and the justifications and limitations of this approach. It is detailed enough to allow replication, shows why these methods are appropriate, whilst highlighting the boundaries of the study.
5. Findings & Discussion	This chapter contains the findings from the data analysis of the transcripts and secondary material. As this is a qualitative research study, the results are reported and discussed at the same time to keep a more reflexive, interpretive stance. It identifies the 6 emerging themes which lead to the formulation of a practical toolkit
6. Outcomes	The outcome of this research is both a contribution to knowledge and a practical toolkit. The contribution to knowledge considers

	whether the findings extend, refine or challenge existing literature. The practical contribution is a set of guidelines that companies building an ecosystem around an innovation should consider.
7. Conclusions	This chapter concludes this thesis by considering how the aims of the research have been achieved, its relevance and its limitations. It provides directions for future research and where it has made a contribution to existing knowledge

2 Case Study

The focus of this research is a single case with multiple units of analysis. The case is focused on the ecosystem surrounding innovation in the construction industry whilst the multiple units of analysis are the companies identified as involved in the ecosystem as disruptive innovators, incumbent firms and the wider ecosystem actors.

Although the number of new technologies being introduced into construction is wide and varied, this research focuses on two; 3D Construction Printing (3DCP) and Building Information Modelling (BIM). A brief introduction for both innovations is presented to provide the reader with context.

2.1 Digitalisation and Innovation in the Construction Industry

Construction is a key industry in countries across the world with an estimated 13% of the world's GDP or $10 trillion in global construction related spending each year (MGI, 2017). The construction sector has historically taken a conservative approach to product design and delivery, leading to a fragmented industry and a disconnected approach to project management (WEF, 2016). Engineering and Construction (E&C) are the world's largest consumer of raw materials and other resources, using approximately 50% of global steel production and more than 3 billion tonnes of raw materials. Even small increases in productivity through adopting innovative processes will have a major impact. Increasing efficiencies can also have an positive environmental effect as buildings are responsible for 25-40% of the world's total energy consumption whilst construction contributes approximately 30% to global greenhouse gas emissions (WEF, 2016).

Without immediate action the impact on the world and its resources will only get worse as the construction industry is expected to expand massively, with estimated revenues of $15 trillion by 2025 and employees numbering over 100 million people worldwide (WEF, 2016). Megatrends in population growth imply an increased infrastructure yet the global shortfall in infrastructure capacity is estimated to reach $15-20 trillion by 2030. Eliminating this could create an beneficial economic boost of up to 100 million extra jobs and generate an extra $6 trillion a year in economic activity (WEF, 2016).

In the UK alone, the construction sector accounts for £370 billion turnover, contributing £138 billion to the economy and employing 3.1 million people or 9% of the total UK workforce (IPA, 2017). However, a lack of R&D and investment in innovation has led to low productivity, low predictability, structural fragmentation resulting in low margins as well as a poor image (Farmer, 2016). Whilst productivity in other sectors such as retail,

manufacturing and agriculture has risen by 1500% since 1945 in the USA, construction productivity has barely increased at all (MGI, 2017). See Figure 2.1 below for graph on labour productivity by sector.

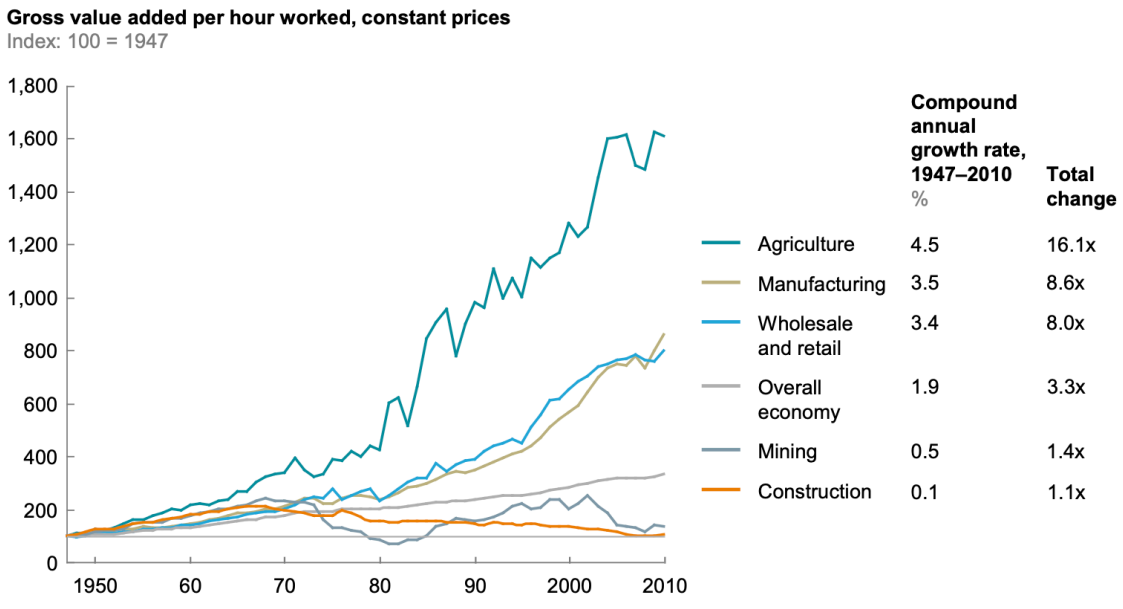


Figure 2.1 Labour Productivity in USA by Industrial Sector (MGI, 2017:23, E9)

As the construction industry accounts for 7% of the world's working population, it has a large impact on the world's available labour force as well as materials, goods and machinery, to construct the infrastructure around us. Unfortunately for the developed nations, labour skills and shortages will be soon apparent with an expected decline of 20-25% of the UK's skilled construction force in the next 10 years (Farmer, 2016) with approximately 30% of UK born workers aged 50 or over whilst 11% are non UK nationals (IPA, 2017). For such an important sector, it is therefore vital to see high productivity, high efficiency, high quality, high sustainability, low waste and low environmental impact through the use of every technological innovation and process available to the construction sector. McKinsey estimate that if construction labour productivity was to catch up with the progress made in other sectors, this could add $1.6 trillion value per year to the world's GDP (MGI, 2017). Yet growth in construction labour productivity has only averaged 1% per year over the past 20 years compared to an average growth rate of 3.6% each year for manufacturing (MGI, 2017).

Causes for low construction productivity include high regulation, inefficient design and investment processes and underinvestment in digitalisation and innovation (MGI, 2017:62). Productivity could be boosted by 50-60% if the construction industry can innovate in areas such as regulation, design, engineering and procurement processes

as well as by embracing new digital technology, materials and automation. See Figure 2.2 below (MGI, 2017:7, E5). This thesis is aimed at researching how innovative firms are addressing these points.

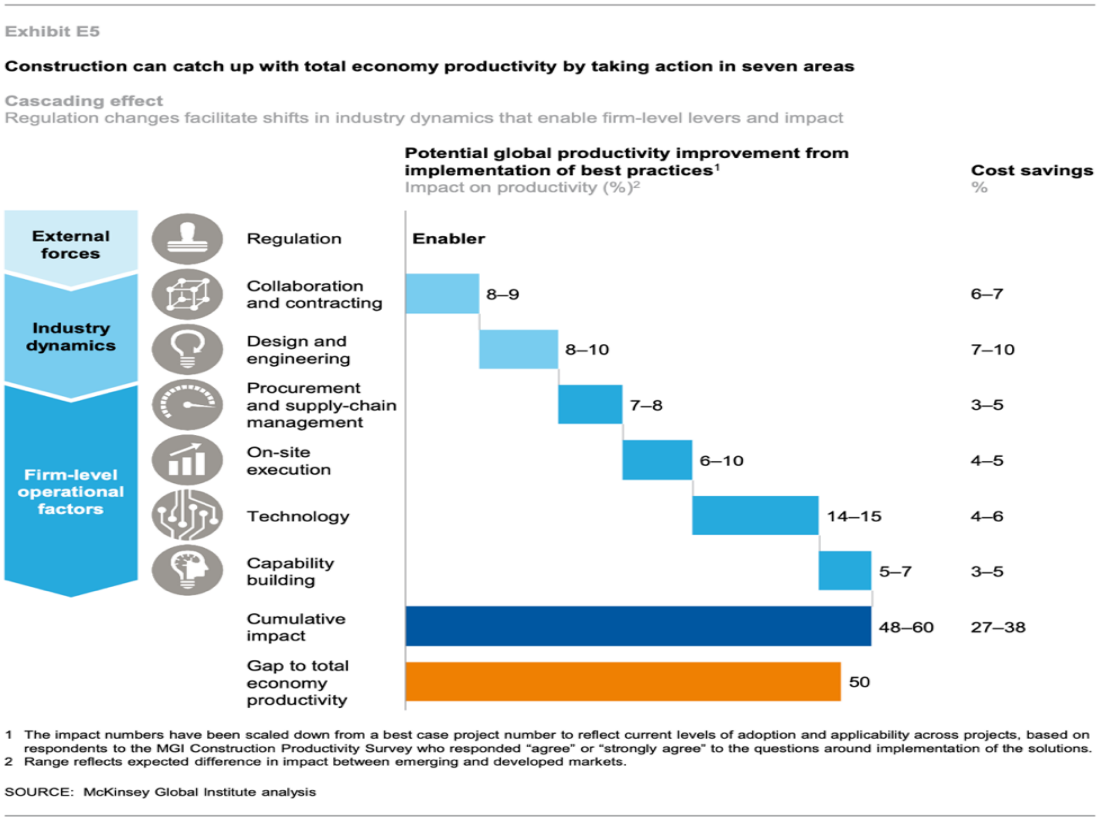


Figure 2.2 Productivity Benefits from Implementing Best Practice (MGI, 2017:7, E5)

Digital technology investments have been identified as the largest contributor to increase productivity (by 14-15%) with a concurrent reduction of associated costs of 4-6%. As the construction industry is currently the least digitised sector after agriculture, this shows the potential from the implementation of digital technologies is immense (MGI, 2017).

Through digitalisation, innovative technologies, and new construction techniques, the industry can improve productivity and efficiency. Standardisation, modularisation and prefabrication are all modern methods of construction (MMC) that could boost the low productivity seen in construction. The benefits of the standardisation of components include cost reductions, fewer tolerance and interface issue, reduced maintenance costs and more recycling. Modularisation increases the customisation and flexibility and increases the potential of prefabrication in a factory-like environment. Prefabrication leads to construction efficiency, through optimised sequencing of the construction process. It eliminates weather-related holdups, reducing delivery times and construction costs in a safer working environment (WEF, 2016).

3D construction printing (3DCP), Building Information Modelling (BIM), and other innovative technologies, automated equipment and advanced building materials are now starting to emerge. Adopting these innovative technologies leads organisations to increase their productivity, streamline their project management processes and enhance quality in a safer working environment (WEF, 2016). Already the construction industry is seeing a trend towards automation and digitalisation which is attracting new types of companies with skillsets not usually associated with this industry. Companies involved in robotics, automation, artificial intelligence (AI), virtual and augmented reality (VR/AR) and Cloud technologies are starting to invest time and resources to provide products and services to enable a more efficient and cost-effective building process. Whilst this research is specifically focusing on BIM and 3DCP, the speed of progress and the adoption of digital technologies has now evolved into a broader term for Digital Engineering, defined as "*the process that delivers an integrated set of geometric model data and documentation that builds over the life of a project capturing all knowledge related to a particular asset during the design, manufacturing, construction and the asset management phases*" (Chakravarty, 2017:Paragraph 12).

Digital tools are being developed in conjunction with BIM to create a *reality mesh* interface between the real and the virtual world, where physical and digital objects interact in real time to help professionals plan, design, construct and operate projects in a safer and cost efficient manner (Chakravarty, 2017). With construction firms increasingly looking for digital engineers this implies a need for training and development of employees in a wider range of skills, including data and systems integration, project management, as well as 3D modelling, construction and design. Future employees will need a broad understanding of these emerging technologies to select and implement the best digital tools to capture value through increased efficiency (Russell, 2019).

The UK government has also recognised how new technology and innovation offer a huge opportunity where faster construction and higher performance at the lowest whole life cost will boost the productivity of the construction sector whilst tackle the identified labour shortages (IPA, 2017). Through its Transforming Infrastructure Programme (TIP) the UK Government aims to boost the construction industry productivity to deliver cost savings of £15 billion per year on its £600 billion infrastructure investment pipeline. TIP has a 10 year scope and attempts to address the barriers that stymie the productivity and efficiency of UK construction through the use of digital technologies and innovation (pbctoday, 2018b). The UK government has committed to invest £170 million to support innovation in the construction sector, including the development and commercialisation of digital and offsite manufacturing technologies (IPA, 2017). The

Construction Industry Training Board (CITB) in the UK believes the next 5 years are crucial in the adoption process of these technologies and sees the fastest approach coming from decisive action now leading to rapid *disruption* and 100% construction sector adoption within the following 10 years (Radley, 2019).

However, innovation in the construction industry is currently constrained by deep-rooted barriers, including underinvestment in R&D, a highly fragmented sector, and widespread risk aversion. To seize the opportunities firms must embed innovation throughout the company and its wider value chain, strengthen the links between suppliers and customers and reconfigure the risks for collaborative partner who adopts these new innovations (MGI, 2017:102). A survey of the barriers and bottlenecks to adopting new technologies (MGI, 2017) highlights several of the issues to be addressed in this research study (See Figure 2.3 below).

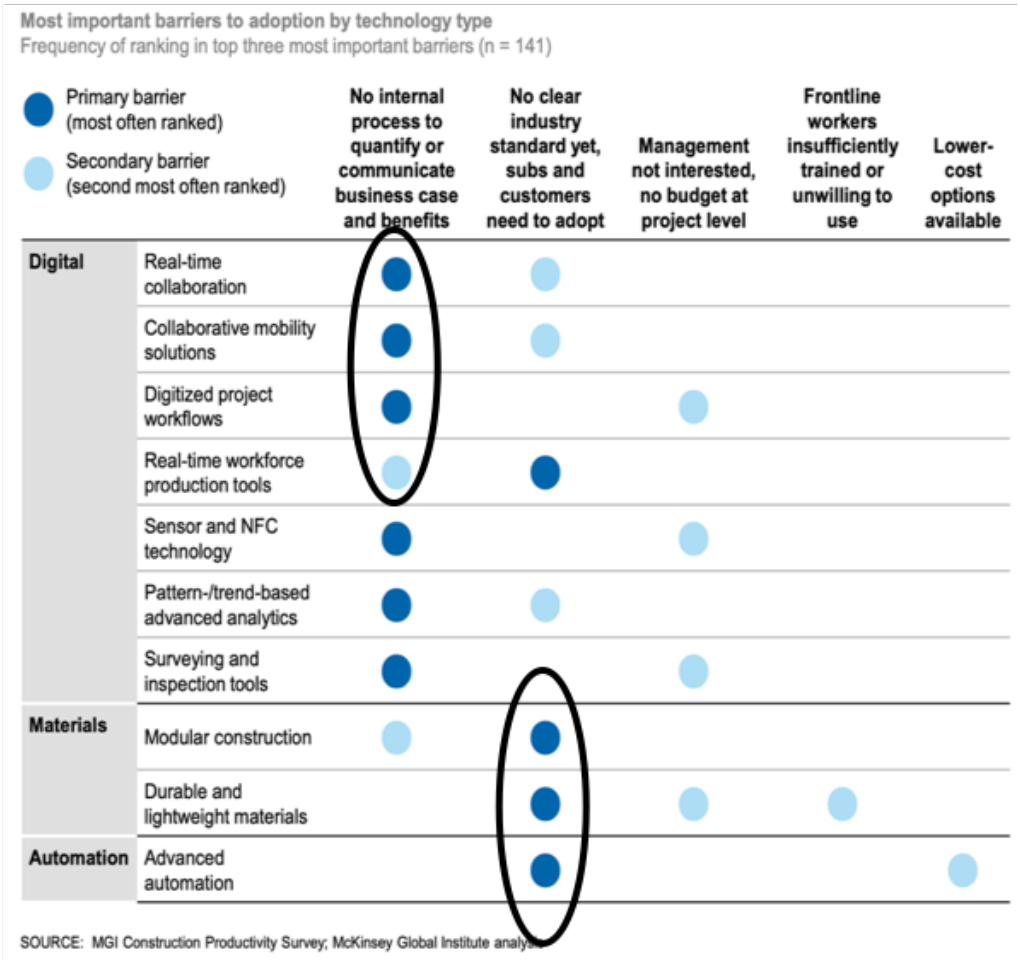


Figure 2.3 Barriers to Digital Innovation in Construction (MGI, 2017:104, E43)

This research study aims to test the suggestions and recommendations of the industry reports as well as apply the existing theories through two specific disruptive innovations: Building Information Modelling (BIM) and 3D Construction Printing

(3DCP). BIM represents a digital twinning approach to improve the whole lifecycle of a building (a disruptive innovation in process) whilst 3DCP represents a totally new way to build houses onsite using advanced automated machinery (a disruptive technology).

As seen from the section above, the construction industry is a prime target for research on innovation. It is seen as conservative, traditional and slow to adopt new technologies. It also has outdated business models compared to other sectors. The question for me was which innovations I should concentrate on as there are many and the construction industry is enormous. I have chosen 3DCP as it represents a very innovative technology at the earliest stages of development. It is an ideal area in which to study the formation of nascent ecosystems. I chose BIM as representative of the other extreme. It is a government led, global initiative to digitalise a low productivity sector that has a huge impact on the daily lives of people across the world. It provides with a completely different value proposition and will affect every firm involved in construction. Both are innovations from a similar time scale with both 3DCP and BIM only seriously considered in the past 10 years, yet both actively pursued at this time in construction industry.

2.2 Innovation in Construction: BIM and 3DCP

The Fourth Industrial Revolution (or Industry 4.0) refers to the automation and information (data) exchange in manufacturing technologies including additive manufacturing (3D printing), whilst web 2.0 includes dynamic or user-generated content on digital platforms that allow users to interact with each other and generate joint value through co-creation (such as BIM). The combination of additive manufacturing integrated with web 2.0 technology will have a disruptive impact on global markets, industrial ecosystems and organisations in the near future (D'Aveni, 2018; Hannibal & Knight, 2018). However, there needs to be a reflection on whether 3DCP and BIM represent sustaining (evolutionary) innovations or disruptive (revolutionary or enabling) innovations.

Sustaining technologies and innovations describe technologies that sustain the current manufacturing practices and technological capabilities in an industrial sector, with incremental improvement of products and services (Bower & Christensen, 1995). This is an evolutionary technology that captures the continuously changing nature of technology (Walsh *et al.*, 2002). Whereas, a disruptive technology *"changes the bases of competition by changing the performance metrics along which firms compete*" (Danneels, 2004:249).

Therefore, disruptive technologies can be considered as more revolutionary as they drive technological change in an industry and are subject to continuous technical improvement but they also enable complementary innovations in other sectors (Teece, 2018b). A technology that enables complementary innovations is disruptive as it upsets the status quo to generate economic and societal benefits. The European Commission has identified six "key enabling technologies" in non-software research fields, including advanced manufacturing, to drive innovation in products across industries and thereby address societal challenges (Commission of the European Communities, 2009 cited in Teece (2018b)). Therefore, 3D printing as an advanced manufacturing process can be considered as a disruptive or enabling technology. Similarly, for a software innovation such as Building Information Modelling (BIM) this can be seen as a disruptive or enabling innovation in the information process of the construction sector value chain, so a collection of complementarity markets is enabled through the adoption of a virtual or digital twin technology.

Previous research finds the degree of disruption depends on the extent to which the new technology changes the affordability of the products produced, thereby affecting consumption, and to what extent the new technology entails a change in the required inputs (Tushman & Anderson, 1986). When 3D printing replaces labour-intensive manufacturing processes this implies a disruption in that industry (Laplume *et al.*, 2016) especially as Gartner Research (Prentice, 2014:02) identified 3D printing as "*a rare example of a single technology that has become truly disruptive by itself.*"

Both BIM and 3DCP represent disruptive technologies to potentially impact the performance of the entire construction industry supply chain with productivity improvements resulting in more efficient manufacturing methods compared to existing technologies (Kothman & Faber, 2016). When Porter (1986) introduced the global value-chain (GVC) concept, he differentiated between dispersed and concentrated global value-chain configurations. Concentrated GVC's describe the highly sophisticated global specialisation of the various value-chain activities of multinational companies. The effect of 3D Printing on GVC's will be substantial and a wide adoption of this technology could potentially reverse the trend towards global specialisation of production systems into more geographically dispersed locations closer to the end-users (D'Aveni, 2015; Hannibal & Knight, 2018). As 3DP technology creates 'whole' products with few intermediate goods this results in shorter global value chains from raw material extraction, processing and distribution straight to 3DP manufacturing of finished goods (Kothman & Faber, 2016; Laplume *et al.*, 2016). Therefore, whilst many new technologies are replacements of obsolete ones, or provide incremental improvements (Anderson & Tushman, 1990), 3DCP and BIM as disruptive or enabling

technologies have the potential to cause a reconfiguration of the entire construction process. 3DCP and other new modern methods of construction (MMC) connected through a BIM platform as the complementary innovation in the information and data analysis process, collaborate so that collectively their individual incremental improvements become significantly more disruptive (Kothman & Faber, 2016).

By replacing most industrial processes this could provide a path to sustainable development for low-income countries (Laplume *et al.*, 2016). This technology could allow market creating innovation in BoP economies, leapfrogging existing global value chains and improving living standards especially in rural areas. *Prosumers* (combined *Producer and Consumer*) could have a substantial economic impact in the near future as 3D printing is used to manufacture products economically in the majority of homes of technically illiterate people (Petersen & Pearce, 2017). As households and 3D print shops adopt the technology they may gain a bigger share of potential industry earnings (Laplume *et al.*, 2016). Fully assembled commercial open source (open innovation) 3D printers can be highly profitable investments for consumers (Petersen & Pearce, 2017) and there is already a trend towards open source platforms, where users and designers co-create products, in other industries. BIM presents a government mandated opportunity to innovate and redesign the whole construction process, through similar co-creation via an information data exchange and in so doing attract new ventures to disrupt the current business model, through the emerging complementary markets in 3DCP, AI, VR/AR, to construct the buildings.

Most empirical research has so far has only focused on 3D printers in developed countries, so this raises the question of what impact a 3D Construction printer available at an affordable cost and accessible to rural areas will have on the construction industry in developing countries. As part of this research I have considered what impact 3DP printers could have on BoP prosumers, living in 3DCP constructed houses with 3DCP constructed workshops containing smaller-scale 3D printers that allow them to manufacture their own products for the local economy. This really is disruption if an environment of innovation can develop to allow this to flourish (Christensen *et al.*, 2019; Hannibal & Knight, 2018).

But as with any disruptive innovation it starts with low-end simple products with the initial processes exhibiting lower capabilities than existing technologies (Christensen, 1997). Capabilities will gradually improve and surpass existing technologies over time. A critical dimension will be the fast delivery of printed parts and structures at the point of use. The US Military as an early adopter is looking into 3DCP as a better, cheaper and faster method of constructing barracks and shelters for its troops operating in remote locations. Many of the companies included in this research are likewise

interested in using 3DCP technology to help refugee camps to quickly and cheaply print shelters for displaced people. As building components are not stored locally and access roads are usually poor, it is logical that rural construction will also favour the same benefits of speed and low cost that these innovations potentially offer.

Incumbent construction companies are currently considering how to integrate BIM in their future business strategies, so now is the opportune time to observe their thought process. Although the manufacturing industry may be considered more relevant for global value chains disruption, the construction industry will also be significantly affected by these disruptive technologies (Laplume *et al.*, 2016). The conservative nature of the construction industry may make adoption of 3DCP and BIM technology a slow process, at least initially (Perkins & Skitmore, 2015) with its application in construction still limited with 3DCP at stage 3: Analysis and Validation based on Mankins (1995) ladder of technology readiness levels so far (Kothman & Faber, 2016). However, the recent examples of buildings printed between 2017-2019 highlights the rapid improvements now being made and why now is the prime time to observe how these pioneers are developing their technology, processes, ecosystems and business models using these two complementary innovations.

2.2.1 Disruption of the Labour Force

One of the most interesting features of 3DCP and BIM technology is its potential to reduce the labour input needed for design and construction of buildings. Over the past fifty years labour productivity in the construction industry has seen stagnation or decline and desperately needs to be addressed if the construction industry is to be able to meets the forecasted requirement for homes and infrastructure. This is due to numerous factors including labourers' resistance to change, poor data interoperability, declining real labour costs and high levels of turnover at the bottom end of the industry (Labonnote *et al.*, 2016). There is also a growing skills shortage in the construction industry compounded by aging populations in the Western countries (Perkins & Skitmore, 2015). Large-scale 3DCP will be able to reduce the amount of personnel required on-site in the hazardous working environments found on construction sites, addressing the safety issues and risk to human life. 3DCP machines are lightweight and can be quickly assembled, disassembled and transported by a small crew. For small residential buildings, the full-scale machine splits into three pieces in order to fit onto a small flatbed truck, minimising the labour required in transportation and logistics (Perkins & Skitmore, 2015) with a fully automated construction operation requiring only minimum human supervision (Zhang & Khoshnevis, 2013). Alongside the other new disruptive technologies now emerging, a redistribution of jobs among workers as well

as a change of roles and required skills will happen. Kothman and Faber (2016) expect the demand for low-skilled workers to decline due to automation whilst demand for high-skilled workers familiar with the new technologies will increase. However (Laplume *et al.*, 2016) finds that labour costs will be low in their research on other 3DP technologies. They examined 3D printing opportunities from three different angles (1) in households, (2) in local print shops and (3) in online print shops with comparison to today's 2D printing. They find that labour costs associated with production using 3D printers is very small, with household productions the most extreme case because it eliminates labour costs completely.

3DP can therefore be considered to be a highly automated technology with a relatively low labour input. This implies there is relatively little to gain from locating manufacturing in low cost labour countries like China, Mexico or India (D'Aveni, 2018). Secondly although the current capital costs associated with 3D printing are relatively high compared with conventional production, capital cost differentials across countries are significantly lower than labour-cost differentials. This leads to new opportunities for co-locating production and consumption within countries. In those industries where 3D printing is both technologically and economically feasible, the technology can induce small-scale local production (Laplume *et al.*, 2016). The creation of very small batches made possible by the customisation available in open source 3D printers opens up new business models catering to customers who desire personalised prints (Kothman & Faber, 2016) leading to a further research possibility of innovation in business model as well as technology and processes.

2.3 3D Construction Printing

3D printing is "*a rare example of a single technology that has become truly disruptive by itself*" (Prentice, 2014:02)

2.3.1 Definition of 3D Printing

Three-dimensional printing (3DP) is an *"advanced manufacturing process that can produce complex shape geometries automatically from a 3D CAD model without any tooling, dies and fixtures"* (Tay *et al.*, 2017:261). For the Construction industry the related term "Additive Construction" is sometimes used to describe *"the process of joining materials to create constructions from 3D model data"* (Labonnote *et al.*, 2016:348). This implies some aspects of the design, production and assembly processes should be digitally controlled. The 3D Printing process can therefore be

defined as follows: (1) a digital 3D model is created by dedicated software, or by the scanning of an existing object, (2) an algorithm cuts the digital model into 2D slices, and (3) a printer prints the object, slice by slice, according to the dimensions of digital 3D model (Labonnote *et al.*, 2016:348).

Similar to 3DP with other materials, the typical 3D concrete printing (3DCP) process has a software and hardware component. Software such as AutoCAD is used to model the object and then it is exported to another software program for 2D slicing. This defines the layer dimensions to generate a program file for the whole object that the printer can read. For the hardware, the gantry or robotic arm printer is connected to the material delivery system, pump and the hose to the nozzle. A controller is required to manage the printer and pump according to the design aspects of the printed object (Paul *et al.*, 2018).

2.3.2 Disruptive Technologies for 3DCP

The main methods for the 3D construction of buildings are Extrusion, Powder Bed, Minibuilders, and Mesh-Mould (Perkins & Skitmore, 2015; Tay *et al.*, 2017). All the companies interviewed in this research study are using an extrusion system with concrete as the building material. Extrusion techniques for construction use a paste-type filament, such as concrete, pumped through a large-format extruder in order to form layers. Four-axis gantry and six-axis robot arm are the most widely used for 3DCP. For large-scale construction the gantry is more suitable due to its simplicity as the printer head can move in any direction, but the base legs do not move. However, for printing complex objects, the robotic printer is more practically suited due to its 6-axis rotational ability (Tay *et al.*, 2017)

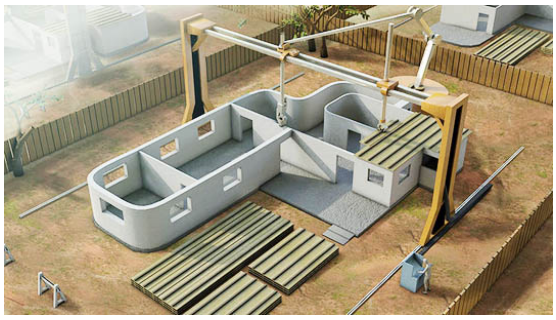


Figure 2.4 3D Construction Printing

Copyright of Contour Crafting and SQ4D

2.3.3 Benefits of 3DCP

The construction industry with regards to residential housing has not really changed in 100 years (Sakin & Kiroglu, 2017). The main advantage of 3DCP, compared to traditional techniques of constructing buildings, is that it can manufacture complex, non-standard geometries rapidly, in an environmentally friendly way, using a printer integrated with a pump, hosepipe and nozzle in limitless designs (Hager *et al.*, 2016; Paul *et al.*, 2018). As human labour can be replaced by digitally controlled robots this allows the implementation of these new techniques in highly polluted or hazardous environments (Perrot *et al.*, 2016). Numerous authors (Hager *et al.*, 2016; Khoshnevis, 2003; Labonnote *et al.*, 2016; Perkins & Skitmore, 2015; Sakin & Kiroglu, 2017; Tay *et al.*, 2017) have listed the advantages coming from developing 3DP in construction and the most important ones include:

(1) Lower costs
    a. Reduced formwork costs in 3DCP construction compared to traditional construction methods
    b. Lower labour costs
    c. Limited material transportation and storage cost on site
    d. Further reduced transportation costs if products are printed on-site
    e. Reduced cost of customized designs

(2) Fewer resources required and less waste implies environmentally friendly construction.

(3) Reduced health and safety risks with substantially lower number of injuries and fatalities on-site as the printers handle the most hazardous and dangerous works

(4) Reduced pollution as 3DP process generate less material waste and dust

(5) Time required to complete the building can be considerably reduced.

(6) On-site or factory applications for high quality mass production.

(7) Potential to create more efficient and interesting designs

One of the key advantages of 3D printing is that it offers the ability to print a “whole” product, thereby not only eliminating the need for assembly but also reducing the need for intermediate goods (Laplume *et al.*, 2016). As this 3D printing allows raw materials to be converted directly into finished goods it dramatically reduces the supply or value chain whilst the increase in the speed of the building process directly leads to an increase in the efficiency of logistics and project management. Environmentally, 3DCP could result in little or no material waste and will be capable of completing the construction of an entire house in less than 2 days for a 200 m^2 two-story building

(Khoshnevis, 2004). As it is estimated that 40% of all raw materials globally are used in the construction industry mainly from dirt converted into bricks (Roodman *et al.*, 1995), with an estimated 3-7 tonnes of waste are generated by the production of a typical single family home (Khoshnevis, 2003), this will have a dramatic effect on the raw materials used in the construction industry. In the future, the potential to embed building utilities including electrical cables and plumbing (Khoshnevis, 2004) reduces the need for first and second fit, eliminating the additional cost of tradesmen and the time to install.

Many of the 3DCP companies have a vision to provide a social benefit to mankind through the cheap and more efficient method of 3D construction of houses. Yet to date there has been little research into social value in construction innovation. Of the 7239 articles listed in the Association of Researchers in Construction Management (2015) database, there is only one reference to social enterprise (Loosemore, 2015). Recent legislation may be instrumental in forcing social value to be considered and the recent introduction of the UK Public Services (Social Value) Act 2012, has resulted in 66% of UK local authorities and housing associations now requiring tenders to consider social value in their procurement processes [Temple and Wigglesworth (2014) cited in Loosemore (2015)].

2.3.4 Examples of 3DCP Buildings

There are still only approximately 20 houses so far completed using 3DCP technology although 2020/21 is likely to see an exponential increase as the number of firms interested in this technology expands. The industry is growing fast with 20 3DCP companies in 2013 growing to 65 by 2018 (Laubier *et al.*, 2018). See Figure 2.5 for four recent examples.

Figure 2.5 Examples of 3DCP Buildings

Copyright (Clockwise from top left): 1. ICON Texas, 2. ICON Mexico, 3. CyBe Italy, 4. WASP Italy

In 2014 the first project to be built entirely by 3DP technology was a Canal House in Amsterdam. Thirteen rooms were printed on site and assembled into one house (Hager *et al.*, 2016).

In 2016 in Moscow, Apis Cor built a 400sqft home. The house was built entirely on site using nothing but a mobile 3D robotic arm printer (Sakin & Kiroglu, 2017).

in 2016 in Dubai, Winsun 3D printed an office in sections in China then shipped. The project was estimated to have reduced labour costs by 50%-80% and construction waste by 30%-60% (Sakin & Kiroglu, 2017)

In 2017 COBOD printed Europe's first 3DCP house in Copenhagen, which meets all current EU building regulations

In 2018 CyBe 3D printed a 100m^2 house in 33 pieces for Milan Design week

In 2018 WASP 3D printed a concept house using clay and rice husks.

In 2018 ICON's prototype 3D house was built in Texas to meet current US housing standards.

In 2019 ICON with their strategic partner NewStory completed two one storey homes in Mexico as part of a planned 50 home development site (December 2019).

In 2019 Apis Cor finished construction of the largest 3DCP building in Dubai, a two-storey office building with 9m high walls (December 2019).

In 2020 SQ4D completed the largest permitted 3D printed home of 1900sqft in only 48 hours (January 2020).

Governments across the world are now looking to this technology to provide a cost effective and fast solution to their housing needs. Dubai wants to 3D print 25% of all government building by 2030 (Dubai Future Foundation, 2019). Singapore plans to build the city's future public housing using large-scale 3D printers to print one story at a time before transporting and stacking each floor on-site (Paul *et al.*, 2018).

Due to its speed and ability to use materials in situ 3DCP has potential in at least two areas: (1) low income housing or emergency sheltered housing; and (2) architectural buildings involving complex shapes that would be expensive to build using traditional methods (Khoshnevis, 2003).

The first 3DCP building in the UK should be printed by 2021 as several local authorities have started to investigate the possibility to print social housing units.

2.4 Building Information Modelling

"BIM has been universally acknowledged as a 'disruptive technology' for the AEC industry, much more than CAD or even computing ever was, and it is causing us all to rethink our processes and identities." (Lachmi Khemlani (AECBytes) cited in pbctoday (2018a:Paragraph 11)).

2.4.1 Definition of Building Information Modelling

Building Information Modelling (BIM) is defined as *"the use of ICT technologies to streamline the building lifecycle processes to provide a safer and more productive environment for its occupants, and to assert the least possible environmental impact from its existence, and to be more operationally efficient for its owners throughout the building lifecycle."* (Arayici & Aouad, 2010:101). It represents an integrated process designed to generate and manage building data from design through construction, lifetime operation, demolition and recycling as well as provide data for facilities management, maintenance, operations and cost analysis (Sakin & Kiroglu, 2017). This can significantly reduce the overall process lead time through integrating each step and make it executable through a single interface (Tay et al., 2017). It is the digital description of every aspect of the physical building leading to the term 'digital twin' or 'virtual twin'. Every aspect from the information for the development, design, and construction phases is collaboratively shared on a platform which is updated in real time (pbctoday, 2018a).

2.4.2 Government Initiatives

The UK Government recognised that the process of moving the construction industry to full collaborative working will be progressive, so defined distinct and recognisable milestones within that process as *levels*. These levels were first introduced in the Government Construction Strategy, *GCS2011-15 or GCS11,* (Cabinet Office, 2011) which intended to reduce the cost of public sector construction projects by up to 20%

and to stimulate the construction sector. Through the definition of four BIM levels ranging between 0 to 3, the UK Government mandated the phased roll-out of Building Information Modelling (BIM), with a requirement for fully collaborative 3D BIM (BIM Level 2) on all centrally procured construction contracts by April 2016.

In effect, the UK Government is using regulation and BIM objectives to digitalise the industry to place it at the forefront of global construction by issuing a series of 'living' documents to act as the blueprint for how this public/private partnership should work with the highest BIM Level 3 to be adopted by the mid 2020's.

The Government Construction Strategy was updated to the current *GCS 2016-20, or GCS16,* (IPA, 2016) as the latest 5 year initiative to work alongside the Construction 2025 Industrial Strategy (BIS, 2013). The Construction 2025 strategy describes how industry and government will work together to place Britain at the forefront of global construction (BIS, 2013). It targets a 33% reduction in the initial cost of construction and the whole life costs of built assets; a 50% reduction in the overall time, from inception to completion, for newbuild and refurbished assets; a 50% reduction in greenhouse gas emissions in the built environment; and a 50% reduction in the trade gap between total exports and total imports for construction products and materials. Alongside GCS16, these two strategy papers have forced the construction industry to start adopting new technologies to meet the BIM Levels and efficiency targets for the construction strategy for 2016-2020 (IPA, 2016).

GCS16 builds on the initial work of GCS11 with new targets to deliver efficiencies of £1.7billion as well as promote 20,000 apprenticeships. It recognises that UK construction is a highly fragmented industry with over 99% of businesses comprised of SMEs (956,000). However as over 25% of construction output is from the public sector, the UK government acts as the biggest single construction client (IPA, 2016). Using this market dominant position, the UK Government can drive change through GCS16 to build on the introduction of BIM levels with BIM 3 as a realistic short-term target.

Results take time to materialise as although GCS11 set a target of reducing the cost of public sector construction by up to 20% by the end of the parliament, this has not been achieved. GCS11 suggested that the public sector accounted for 40% of the total annual £110bn spend on construction in the UK. Therefore a 20% saving should have delivered £8.8bn a year by the end of the parliament. However, GCS16 reported that efficiency savings of just £3 billion were achieved over the entire period 2011-15 (IPA, 2016).

However, progress has been made in increasing awareness of and the use of BIM following the UK Governments actions. In the latest National BIM Report (NBS, 2019), a survey shows that 69% are now using BIM, 23% are aware of it and only 2% are

unaware. Within 3 years, 95% of respondents say they will be using BIM. These numbers compare to just 13% using BIM in 2011 so fast adoption has been achieved through the intervention of UK Government and global initiatives. Since 2017 the promotion of the *Digital Built Britain* plan to transform the UK construction industry to adopt digital technology has begun to make an impact through better use of built assets and provide better social outcomes to face up to the challenges of urbanisation and increasing population.

2.4.3 BIM Levels

The 4 BIM levels, as outlined by the UK Government, represent an increasing use of digitisation and collaboration in a construction or infrastructure project. Within each level there are sub levels or dimensions that are also described. There are now 6 dimensions which must also be recognised when discussing BIM, which unfortunately confuses many people. An illustration showing the BIM Level 0-3 with the related dimensions adds some clarity (See Figure 2.6 below)

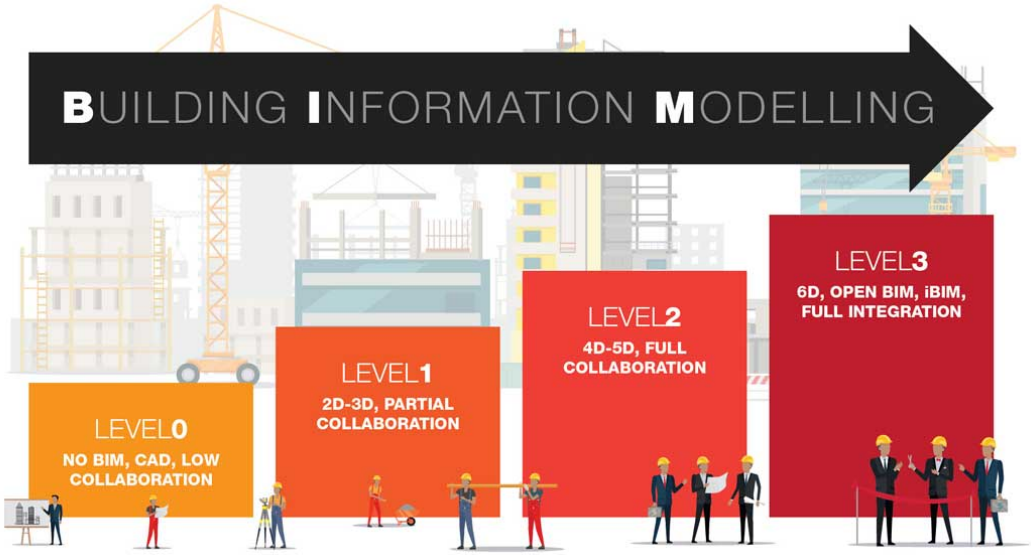


Figure 2.6 What is BIM? (pbctoday, 2018a)

2.4.3.1 BIM Level 0

Projects include very little or no collaboration. The project will use only 2D computer-aided design (CAD) drafting. Any data that is exchanged is typically done so via paper or print. However, the majority of the UK construction industry is already much more advanced than this (NBS, 2019).

2.4.3.2 BIM Level 1

2D BIM represents a project using 2D (usually for statutory approval documentation) paper and print with more digital collaboration including CAD drafting of concept work.

3D BIM represents the 3 dimensions (length, width and height) represented in a virtual twin of a 3D CAD model. They will use a common data environment (CDE) for the electronic sharing of data, usually managed by the main contractor and may be shared among team members. Projects may also use some standard data structures and formats (McPartland, 2017)

2.4.3.3 BIM Level 2

4D BIM adds construction sequencing as a 4th dimension, time. Time related information such as scheduling is added to the components, such as lead time, installation time, sequence of component installation. This helps planning to ensure it is safely, logically and efficiently sequenced (McPartland, 2017)

5D BIM technology adds cost as the 5th dimension. This can include capital, running and replacement costs (McPartland, 2017). The addition of cost and schedule overlays enables 5D BIM to become a powerful visualisation and project-management platform through the life cycle of a project. In the future, 5D BIM can be integrated with augmented- and virtual-reality technology to create seamless interaction between offices and the work site (MGI, 2017).

2.4.3.4 BIM Level 3

6D BIM adds facilities management or project lifecycle information as a 6th dimension. This has been referred to as integrated BIM or iBIM. It involves the inclusion of information to support facilities management and business operations. Information might include manufacturer of components, installation date, maintenance requirements, expected lifespan and decommissioning and recycling data (McPartland, 2017).

Projects at this level are fully collaborative. They use a single, shared project view for data integration, which all parties can access and modify as allowed through process and security controls. Whilst not fully defined, the UK Government expects the creation of a set of new, international open data standards (Open BIM) for easy sharing of data across the entire construction sector. A new contractual framework for projects procured with BIM to ensure consistency, avoid confusion and encourage open, collaborative working.

2.4.4 Key components of BIM

BIM comprises five main areas: People, Processes, Policies, Technologies and Information (See Figure 2.7 below) that collectively form the components for the successful completion of a construction project.

1. People: Collaborative effort of teams to ensure real-time capture and sharing of data amongst the project team, whether in the field or the office.
2. Processes: The reconfiguring of the processes involved in a project including procurement, workforce management, resource control and approvals
3. Policies: The updating of all regulations and standards to provide clear advice and transparency on the requirements for projects from concept to end of life.
4. Technologies: The use of 3D models and innovative technologies to capture and explore co-ordinated planning, design, construction and lifetime usage of a building project
5. Information: The capture and insights for project schedule, costs and facilities management

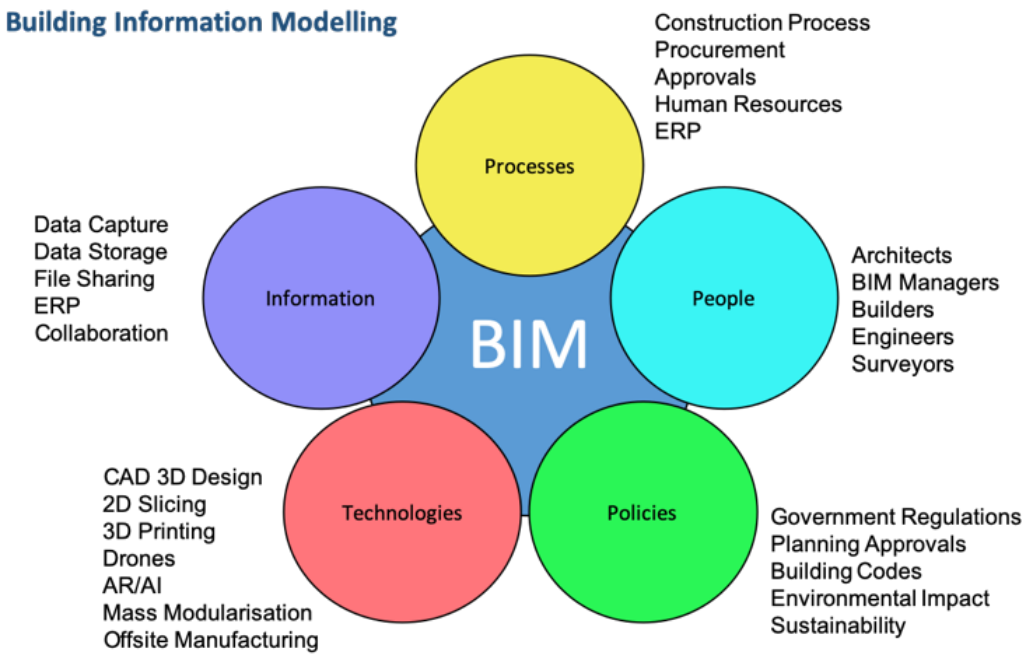


Figure 2.7 BIM Elements (Adapted from Paul, 2018)

Since its conception only a few years ago, BIM has been developed into a globally recognised standard consisting of multiple levels of compliance. These levels are used to distinguish between buildings that have been designed and constructed using traditional processes and methods and those that have adopted the latest digital technologies. Government mandated change has driven the industry to review all the five key areas concurrently. The AEC (architecture, engineering and construction)

industry has seen vast digital development over the past 10 years, with international BIM standards driving these changes (pbctoday, 2018a), unleashing an intelligent 3D model-based process for AEC professionals and thereby providing the tools to more efficiently plan, design, construct, and manage buildings (Autodesk, 2018). With artificial intelligence, augmented reality, automation and innovative digital technologies already revolutionising other industries, these technologies are now branching out into the construction sector via BIM as incumbents and new ventures see the opportunity to reshape the sector.

2.4.5 Benefits of BIM

"Collaboration should be a hallmark of the construction industry itself: the industry's future success will rely heavily on effective collaboration among all stakeholders" (WEF, 2016:4).

Building Information Modelling (BIM) leads to greater collaboration on projects, it results in fewer errors, it allows real time assessment and solution to on-site issues which leads to less rework and corrections resulting in greater efficiencies and therefore reduced costs. Surveys show 48% say BIM has improved their profitability, even though 69% of builders are still looking for manufacturers to provide more BIM components (NBS, 2019). Those using BIM the most report the highest return on their BIM investments and expect BIM related work to increase by 50% on average. Many plan to increase their capital expenditure on their BIM related programs with a focus on internal and external collaboration, mobile hardware and BIM software (MGI, 2017).

However, challenges remain with three of the main barriers to adopt BIM cited as: a lack of inhouse expertise (63%): a lack of training (59%): cost (51%). Other key issues include a lack of demand from clients so far (65%) perhaps driven by a lack of industry protocols and standards (NBS, 2019:32).

The cost of both the hardware and software with VR/AR headsets, bricklaying co-bots and 3D construction printers requires upfront capital investment. Training of the labour force to use the new equipment, which is far removed from those traditionally seen on a construction site is an issue especially for an industry with an older average age workforce. Attracting the next generation to an industry that has traditionally been seen as male dominated and physically demanding may also be difficult. Therefore, the incumbents need to address traditional thinking and business models whilst new ventures need to break down industry stereotypes and overcome barriers if the benefits of BIM and the digitalisation of construction is to succeed. But early adopters

are seeing the benefits in raised productivity, reduced costs and more transparent and efficient processes.

3 Literature Review

3.1 Introduction

The main aim of this literature review is to show why my research needs to be carried out, how I choose the theories to work with and how my thesis can add to the previous knowledge in these areas. This review is a reflection on the existing work in the areas of Business Ecosystems and Disruptive Innovations as these are specifically targeted in my research question 'How do new ventures successfully create an *ecosystem* to capture value from a *disruptive technology*?' This review critically analyses published material and then synthesises it down into this concise chapter of my thesis and helped me identify the specific research relevant to my question. It highlighted the previous studies in similar areas, explains previously developed knowledge, suggested gaps where additional contributions can be made, details research methodologies previously employed in similar studies and is a critical appraisal of previous work (Jackson & Bazeley, 2019; Lee & Lings, 2008; Savin-Baden & Major, 2013).

3.2 Key Findings and Insights

Construction represents one of the biggest industrial ecosystems and is facing multiple strategies to raise productivity through various types of innovation. This was the justification to focus on ecosystems and disruptive innovation and subsequently determine whether existing contributions to knowledge are applicable to this industrial context.

My main findings are that there are various types of innovation and ecosystems. Thirty years of research has fragmented initial concepts by Christensen (1997) and Moore (1993) into multiple sub fields with various levels of applicability to companies in the construction sector. Overall, I find that both *ecosystem* and *disruption* are omnipresent terms which are often misused and that these concepts need better definition and measurability to be useful in a practical toolkit for companies.

I find many of the recent contributions need to reflect more on the antecedent fields of strategy management, namely resources dependency (Pfeffer & Salancik, 1978) and stakeholder theory (Freeman, 1984) especially for ecosystem strategy. Recent research on the theory of ecosystems (Adner, 2017; Jacobides *et al.*, 2018) is still too conceptual and leaves unanswered questions on how to measure the strength of the bonds between ecosystem actors. My insights are aligned to emergent research on the similarities and differences of ecosystems and interorganisational networks when viewed through the strength of network links and interdependencies (Shipilov & Gawer,

2020). I find that Moore's (1993) initial definition of three ecosystem layers can be extended using more recent social network and complexity theory (Barabasi, 2014; Russell & Smorodinskaya, 2018) into six layers with corresponding degrees of network strength. This allows a review of the type of ecosystem and the level of disruptiveness of key players in that ecosystem to provide a typology and axiology of how ecosystem and innovation type can be practically conceptualised by a firm as part of its business strategy.

3.3 Historical Origins

Adam Smith is rightly called one of the fathers of economic theory for his seminal work in *Wealth of Nations* (Smith, 1776) which outlined the role and purpose of the free market and how producer competition, free from regulation and border restrictions, can improve the wealth of a nation. He believed a successful economy can be formed through the '*self-interest*' of its individuals to improve society.

Joseph Schumpeter helped define the role that innovation and entrepreneurs play in the economic development of nations in his work on *The Theory of Economic Development* (Schumpeter, 1934). Entrepreneurs or innovators create new products that upset the status quo of the existing economic circular flow and through this *disruption* allow advances in the growth and prosperity of nations and communities. He later coined the phrase '*creative destruction,*' to describe as *"the process of industrial mutation … that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating the new one. This process of creative destruction is the essential fact about capitalism"* (Schumpeter, 1942:83). This explains how the economy, through the actions of these innovators, has a perpetual cycle of instability and dynamism rather than remaining static, with industry constantly reacting to innovation.

Christensen further developed Schumpeter's concept by suggesting that *disruptive technology* is the force behind creative destruction (Christensen, 1997) when new products initially aimed at the non-consumer can move up the technology chain until the incumbents are forced to either adopt similar technologies or risk being displaced. He observed that traditional business strategies surrounding '*sustaining technologies'* (listening and responding to customers, focusing resources on activities that maximize profit) are not optimal when faced with disruptive technology. *"It is in disruptive innovations, where we know least about the market, that there are such strong first-mover advantages. This is the innovator's dilemma"* (Christensen, 1997:296). Nearly 250 years after Adam Smith, Christensen strikes a familiar note when he proposes that

it is through innovation and entrepreneurial ambition (self-interest?) that nations can rise out of poverty (Christensen *et al.*, 2019).

Over the past 20 years the disruptive innovation concept has been intensively researched, debated, revised and expanded to include other forms of disruptive innovation, such as process or business model innovation, as well as technology as the driving force behind industry change (Christensen & Raynor, 2003; Christensen *et al.*, 2018). Specifically, technologies and business models must be connected as disruptive innovations must be evaluated relative to a firm's business model. In his latest collaborative work in *'The Prosperity Paradox, How innovation can lift nations out of poverty'* (Christensen *et al.*, 2019:17) he extends this work to describe three types of innovation that can be observed in industry that shapes the business model: *sustaining, efficiency, and market-creating*. The third type of innovation are market creating innovations which logically create new markets. Market creating innovations allow a simplified product compared to existing ones, which are cheaper and more accessible so that many more people are able to buy and use them and therefore represent the highest level of disruption to improve society (Christensen et al., 2019).

Yet innovators are often not rewarded for their new products or services, as much as imitators, customers and other industry participants (Teece, 1986). So, scholars have also researched how companies develop their business and forge relationships with customers, suppliers and other interested parties to allow them to capture value from their new innovation and gain traction in the market before another competitor rushes in. Aa a firm's competitive advantage depends on its ability to create more value than its rivals, the greater the firm's ability to innovate should result in greater added value (Porter, 1985).

However, this is not the sole contributor to success as the firm's external environment plays a significant part. These external factors for success rely on an interdependent *business ecosystem* involving other players (Adner, 2006). James Moore (1993:76) in his seminal article '*Predators and Prey'* first conceptualised a business ecosystem, in terms usually associated with ecology, where "*companies co-evolve capabilities around a new innovation: they work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations.*" This field of research has expanded since the early 90's to build on theories of networks, alliances and key stakeholders to consider how companies develop both internal and external capabilities and how they negotiate the minefield of co-operation and competition to allow their company to capture value from a new innovation or technology. As the players in an ecosystem have different primary roles and interdependences, the concept of an ecosystem centres around a common value

proposition. This value proposition can be a structure or an affiliation (Adner, 2017) but remains the key link between the players in a complex network. Recent work, including this study, has tried to link the fields of disruptive innovation and ecosystems to provide a framework for how companies can create and capture value from innovations (Adner & Kapoor, 2010; Jacobides *et al.*, 2006). However, there are still many gaps in the literature for research studies, especially concerning new ventures and their nascent ecosystems trying to capture value from an innovation especially in the construction industry. To identify all existing knowledge and uncover limitations and gaps, I conducted a systematic literature review.

3.4 Systematic Literature Review

For the fields of business ecosystems and disruptive innovation the majority of scholarly articles have been written after 1990, so they are relatively recent additions to the wider academic literature on strategy and entrepreneurship. In order to determine relevant literature for my particular research question, I conducted a systematic literature review (SLR) following the methodology of Tranfield, Denyer and Smart (Tranfield *et al.*, 2003) and (Petticrew & Roberts, 2006). These authors define processes, common for the medical sciences and several other disciplines, to develop a systematic way to review literature in management and the social sciences. Three of the most common reasons to conduct a systematic review are:

"(a) When there is a wide range of research on a topic but key questions remain unanswered (b) When a general overall picture of the evidence in a topic area is needed to direct future research efforts and (c) When an accurate picture of past research, and past methodological research is required to promote the development of new methodologies" (Petticrew & Roberts, 2006:35). My research fulfils all three criteria.

I used the Web of Science (WoS) Core Collection database as it has over 1.4 billion cited references from 20,000+ journals. My review covered a timescale of 30 years from 1989-2019 for a preliminary search of English language articles. Other databases and languages are available, and I accept that use of just WoS and English are limitations when conducting a full systematic review.

For a cross check on relevance of the keywords to be used in the WoS searches, I analysed recent reviews on websites for the International Journal of Management Reviews and Google Scholar with multiple sample keywords and then selected the most relevant articles. This helps prevent conducting a systematic review that may already exist as there is no point in repeating the same work. This can also be useful in

emergent fields of research where keywords may not yet be standardised, as may be the case in both disruptive innovation and business ecosystems, as concepts and definitions are still being discussed. For my review the most relevant systematic review articles were; Ecosystems (Scaringella & Radziwon, 2018), Innovation Ecosystems (Dedehayir *et al.*, 2018; Gomes *et al.*, 2018), Low end Innovation (Reinhardt *et al.*, 2018), Disruptive Innovation (Yu & Hang, 2010), Alliance Portfolios (Wassmer, 2010), Networks (Provan *et al.*, 2007), and for 3DCP (Labonnote *et al.*, 2016; Tay *et al.*, 2017). This allows a strong representation of existing peer reviewed scholarly articles on the broader topics before cross analysis of articles to reduce the scope to relevance to my research question.

After considering all the terms used in existing articles, I constructed my list of keywords, as shown in Table 3.1. Use of asterisks and Boolean functions helped ensure the widest selections of potentially relevant articles were included.

Table 3.1 Keywords for Web of Science Search

Field of Research	**Keywords for search**
Business Ecosystem	Business ecosystem*, innovat* ecosystem*, entrepr* ecosystem*, innovat* manage*, business model innovat*
Resource Dependence Theory Stakeholder Theory	Resource dependenc*, stakeholder*
Alliance Portfolio, Network	Alliance portfolio*, alliance network*, alliance web*, strategic alliance*, inter-firm/ organi*ation*
Disruptive Technology	Disrupt* tech*, disrupt* innovat*
3D Printed House Construction	3d print* hous*, concrete print*

Once the initial keyword searches were run on the 14th April 2019, search strings using multiple keywords were used to reduce the overall number of articles (Figure 3.1 below). Pairs of keywords were initially run, followed by three or more terms. Whilst this could have been immediately run using longer search strings, I prefer to use pairings initially to ensure keywords are relevant and producing meaningful data.

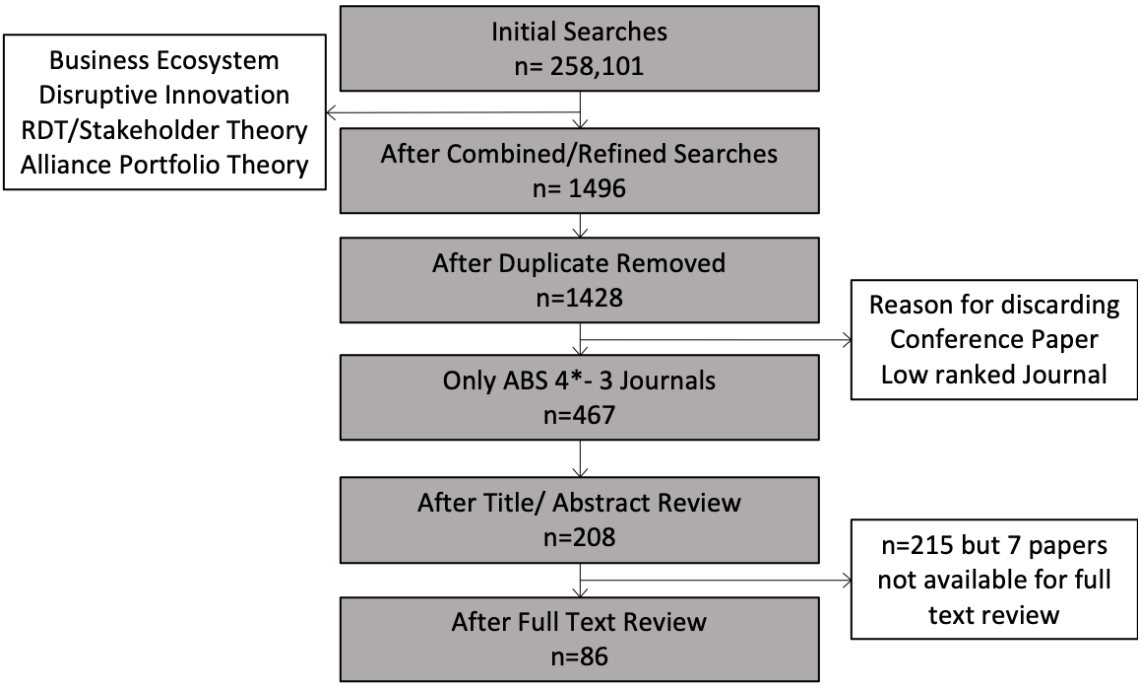


Figure 3.1 Systematic Literature Review Process

As a quality check the 1428 initial articles listed were compared against the Chartered Association of Business Schools Academic Journal Guide 2015. Selecting only the articles published in journals ranked 3 to 4* reduced the list to 467 articles

The methodology to review this reduced list of articles consisted of 4 stages;

(1) Scan for keywords and themes in Title (2) Read through Abstract for relevant themes (3) Explore the full text for themes (4) Record relevant data pertaining to my research question (Rajwani & Liedong, 2015).

After reading the majority of the articles at least twice the articles were categorised by relevance for field, focus and findings: 215 Relevant, of which 86 were considered useful for this thesis. As a further check, I read across a wide range of literature including secondary information sources such as books, government reports, websites and press releases from relevant companies to ensure that the literature review did not miss any key articles cited by leading academics in this field.

The aim of this literature review is to see how existing articles fit together and how it can be synthesised into my research question (Lee & Lings, 2008). However, too many non-relevant references shows poor scholarship and an inability to separate the meaningful from the marginal (Bloomberg & Volpe, 2008) as a lengthy literature review which has a huge number of citations is not as good as one that identifies the key citations and treats them fairly (Yin, 2018). Mindful of this, whilst I have read and analysed hundreds of articles, including those from this SLR, to ensure a rigorous review only the most significant articles are included.

To help understand the research already carried out, its key findings and the sector that has been analysed I extracted key information from the reviewed articles such as *Topic, Research Question, Setting, Key Findings* and coded them in Excel (Savin-Baden & Major, 2013). See an example from my spreadsheet below in Table 3.2 below:

Table 3.2 Example of Extracted Information from Journal Articles

Search String	Rank by Times Cited	Publication Type	Author	Title	Keywords	Topic	Research Type	Theory Area 1	Theory Area 2	Methods	Sector	Key Findings
BusEco	1	J	Teece, David J.	Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance	Dynamic Capabilities,Sense, Seize, Transform	Dynamic Capabilities	Conceptual	Dynamic Capabilities	Ecosystem	Framework	General Business	Microfoundations of businesses. Need for dynamic capabilities. Managing their ecosystem
BusEco_DisTech	1	J	O'Reilly, CA; Tushman, ML	The ambidextrous organisation	Ambidextrous. Paradox of evolution and revolution, Discontinuities	Disruptive Innovation	Conceptual	Disruptive Innovation	Ambidexterity	Case Study	General Business	Different types of innovation framed from case study research. Ambidexterity used to explore and exploit
BusEco	2	J	MOORE, JF	PREDATORS AND PREY - A NEW ECOLOGY OF COMPETITION	Ecosystem definition, 4 stages, Cooperation and competition, bargaining power	Ecosystem	Conceptual	Ecosystem		Framework	General Business	4 stages of an ecosystem
BusEco_DisTech	2	J	Johnson, Mark W.; Christensen, Clayton M.; Kagermann, Henning	Reinventing Your Business Model	business model innovation, radical new tech needs a new business model, 4 elements customer value proposition, profit formula, key resources, key processes. The tata car 1 lakh	Business Model	Conceptual	Business Model		Framework	Tata Cars	A radical innovation needs a new business model as well to succeed
BusEco	3	J	Adner, Ron; Kapoor, Rahul	VALUE CREATION IN INNOVATION ECOSYSTEMS: HOW THE STRUCTURE OF TECHNOLOGICAL INTERDEPENDENCE AFFECTS FIRM PERFORMANCE IN NEW TECHNOLOGY GENERATIONS	Ecosystem strategy, other innovators, focal firm relationship, value creation, components and complements, bottlenecks	Ecosystem	Empirical	Ecosystem	Innovation	Quantitative	SemiConductor Industry	Value creation dependent on ecosystem position
BusEco_DisTech	5	J	Christensen, CM; Bohmer, R; Kenagy, J	Will disruptive innovations cure health care?	incumbent inertia, business models, sustaining vs disruptive innovation,low cost care	Disruptive Innovation	Conceptual	Disruptive Innovation	Ecosystem	Framework	US Health Sector	Rethink practices to allow disruption into US healthcare

Using the key information extracted from the articles, I analysed the various fields to detect any patterns of research. See Table 3.3 and Table 3.4 for a list of main topic and theory fields. Many of the articles involved a second research theory with only 32 of the 86 identified using a single research field. As can be seen from the combined theory articles, 29 of the remaining 54, use a combination of the three main theory areas with the rest encompassing a wide range of other theories from dynamic capabilities to options theory.

Table 3.3 Literature Review Articles Breakdown by Theory Fields

Single Theory Articles	Count	%
Disruptive Innovation/Tech	19	22%
Ecosystems	10	12%
Business Model	3	3%
Single Theory Articles (of 86)	32	37%

Combined Theory Articles		Count	%
Disruptive Innovation/Tech	Ecosystems	16	19%
Disruptive Innovation/Tech	Business Model	8	9%
Business Model	Ecosystems	5	6%
Combined Theory Articles (of 86)		29	34%

Table 3.4 Literature Review Articles Breakdown by Main Topic

Main Topic	Theory 1	Theory 2	Count	%
Business Model	Business Model		3	3%
Business Model	Business Model	Disruptive Technology	3	3%
Business Model	Business Model	Ecosystems	2	2%
Business Model	Business Model	Innovation	2	2%
Disruptive Innovation	Disruptive Innovation		17	20%
Disruptive Innovation	Disruptive Innovation	Ecosystems	7	8%
Disruptive Innovation	Disruptive Innovation	BoP	4	5%
Disruptive Innovation	Disruptive Innovation	Business Model	3	3%
Disruptive Innovation	Disruptive Innovation	3DP	2	2%
Disruptive Innovation	Disruptive Innovation	Strategy	2	2%
Disruptive Innovation	Disruptive Innovation	Ambidexterity	1	1%
Disruptive Innovation	Disruptive Innovation	Cognition	1	1%
Disruptive Innovation	Disruptive Innovation	Dynamic Capabilities	1	1%
Disruptive Innovation	Disruptive Innovation	Open Innovation	1	1%
Disruptive Innovation	Impression Management	Real Options Theory	1	1%
Disruptive Technology	Disruptive Technology		2	2%
Disruptive Technology	Disruptive Technology	Ecosystems	2	2%
Disruptive Technology	Disruptive Technology	Dynamic Capabilities	1	1%
Disruptive Technology	Disruptive Technology	Technology Forecasting	1	1%
Ecosystem	Ecosystems		10	12%
Ecosystem	Ecosystems	Innovation	5	6%
Ecosystem	Ecosystems	Business Model	3	3%
Ecosystem	Ecosystems	3DP	2	2%
Ecosystem	Ecosystems	Leadership	2	2%
Ecosystem	Ecosystems	Complexity Science	1	1%
Ecosystem	Ecosystems	Open Innovation	1	1%
Ecosystem	Ecosystems	Opportunity	1	1%
Ecosystem	Ecosystems	Strategy	1	1%
Ecosystem	Organisation Theory	TCE	1	1%
Open Innovation	Open Innovation	Ecosystems	1	1%
Dynamic Capabilities	Dynamic Capabilities	Ecosystems	2	2%
		Total	86	100%

Table 3.5 highlights that most research into disruptive innovation and ecosystems is conducted using qualitative rather than quantitative methods with only approximately 8% using quantitative and only 2% employing mixed methods. Of the 85% using qualitative methods, case study is the most popular with 35% of the total. A large number of the articles also point to conceptual frameworks as their output (34%). As I want to provide a practical toolkit, I have also taken an inductive qualitative case study

approach to answer this research question, which is explained in detail in the Methods Chapter.

Regarding the context for the research, only 3 articles were focused on 3D printing (not 3DCP) and only one for general construction with the majority either general business (50%), technology (27%), or automotive (9%)

Table 3.5 Literature Review Articles Breakdown by Method

Method	Count	%
Case Study	30	35%
Framework	29	34%
Theory	14	16%
Quantitative	7	8%
Systematic Review	4	5%
Mixed Methods	2	2%
Total	86	100%

3.5 Theoretical Lenses

As the results show a large percentage of articles related to the triumvirate of disruptive innovation, ecosystems and business model, I have reviewed all three theoretical lenses to conduct a rigorous review, for this research study to add a contribution when assessing how the construction industry adopts new innovative techniques.

It can be seen from Table 3.3 that ecosystems and business model are frequently interconnected fields of study when researching disruptive innovation, especially as researchers moved away from the actual technology and more towards the whole business model process (Christensen & Raynor, 2003; Christensen *et al.*, 2015). However, it can also be seen that a wide range of theoretical lenses have been applied ranging from ambidexterity (O'Reilly & Tushman, 2004) and dynamic capabilities (Teece, 2007) which align more with the internal skillsets within the companies, to more esoteric areas such as impression management (van Balen *et al.*, 2019) or managerial cognition (Vecchiato, 2017). For articles with business ecosystem as the main topic there has also been a widening of secondary theoretical lenses. Whilst business model and innovation are again the main complementary areas, scholars have used strategy (Adner, 2017) and complexity science (Russell & Smorodinskaya, 2018) as adjacent fields. Of interest to this research is the number of articles related to 3D printing and Base of the Pyramid studies that are starting to emerge in relation to both disruptive innovation and ecosystems such as Hannibal and Knight (2018).

However, I was surprised by the limited number of articles employing complex networks or ecological studies derived from the natural sciences as a reference point

considering Moore's (1993) initial comparison. I was also surprised by the relatively few articles that have explored difference between alliances, partnerships and ecosystems with some notable recent exceptions (Adner, 2017; Jacobides *et al.*, 2018). Other areas that were referenced but not explicitly detailed were those relating to resource dependence and stakeholder theories (although many implicitly or briefly mention them), which I had also used in the search strings, as I consider them to be antecedents to the development of ecosystem theory. These both come under the umbrella of strategy and strategy management, which are key to a new venture deploying a new technology. I briefly describe these two antecedent theories here to highlight relevant similarities which will become apparent later when considering the full description of disruptive innovation and ecosystems.

3.5.1 Resource Dependence Theory

Resource Dependence Theory overlaps with business ecosystems as the unit of analysis is the interdependences of actors in and surrounding and firm. Therefore, it is an important antecedent field of study. In introducing the re-release of the seminal book '*The External Control of Organizations'* (Pfeffer & Salancik, 1978) after 25 years, Pfeffer (2003:47) reflected on the main contributions the book has had. It relied on three central themes, (1) viewing organisations as embedded in networks of interdependencies and social relationships, dependent on the external sources of resources (financial, physical resources, information) leading to the *resource dependence theory (RDT)* (2) organisations whilst constrained by their situations and environments could seize co-opting opportunities to pursue organisational interests (3) the importance of the construct of power for understanding both intra-organisational and inter-organisational behaviour.

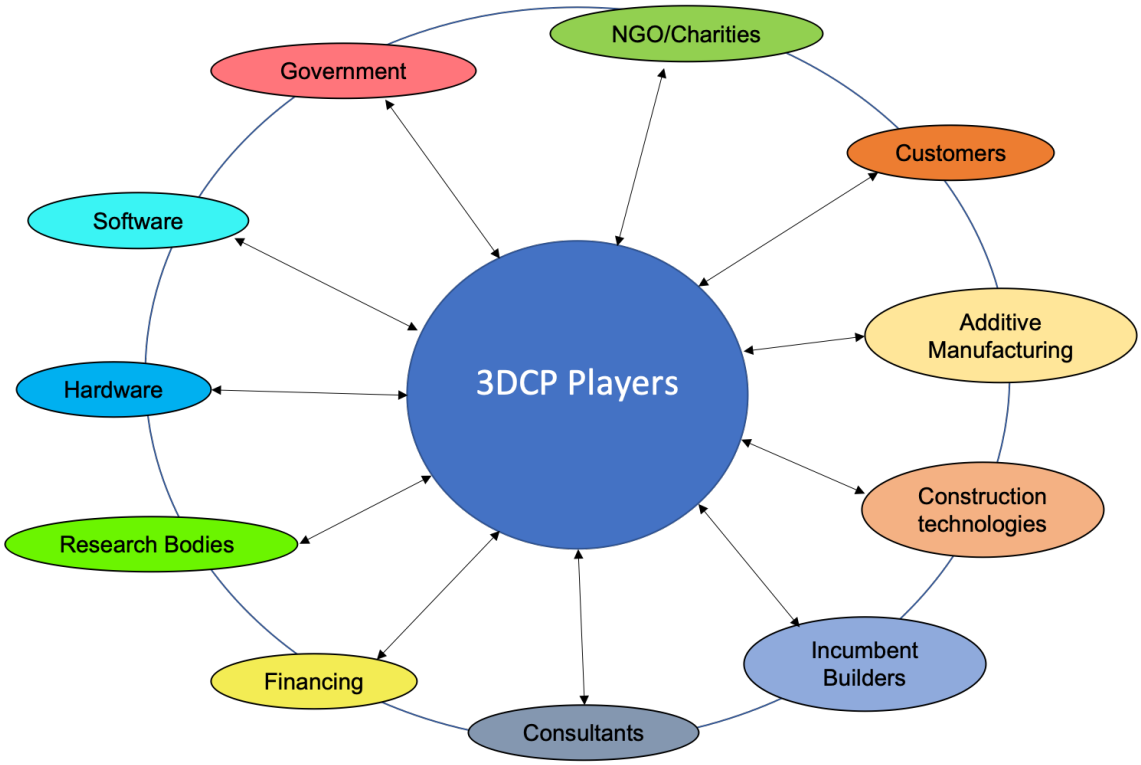
Interestingly in his introduction Pfeffer (2003) also highlights how Christensen's work on sustaining and disruptive technologies (Christensen, 1997) are compatible with RDT as although firms leading the disruption tended to be disruptors rather than incumbents, the incumbent firms ability to enact strategic change is restrained by the interests of external entities (customers) who provide the resources the firm needs to survive (Christensen and Bower (1996 p212) cited in (Pfeffer & Salancik, 2003)).

However, their central thesis also uses the analogy of biological ecosystems by stating that *"to understand the behaviour of an organisation you must understand the context of that behaviour… the ecology of the organisation"* (Pfeffer & Salancik, 1978:01). An organisation's ability to be effective and survive depends on the demands of interested groups upon which they rely on for resources and support and how they acquire and

maintain those resources especially in a changing environment (Pfeffer & Salancik, 1978). This seems close to an ecosystem approach to me with both internal and external factors driving the value proposition of the company. A company's organisational effectiveness and organisational environment has an effect on its activities and their outcomes. The importance of the environment in which a firm operates also determines how it will perform (Pfeffer & Salancik, 1978). As enterprises are constrained and affected by their environments and as new enterprises lack all the resources needed to build a full value chain, they must rely on their external network of interdependencies and social relationships. This requirement for tangible financial and material resources, and intangible resources such as information and technical know-how, is the basis for resource dependency with the firm dependent on a variety of firms for resources. As a focus firm matures and tries to alter its environment (and therefore its ecosystem) a dynamic interplay of networks, alliances and negotiations emerges through Moore's (1993) four stages.

3.5.2 Stakeholder Theory

Another resurfacing field that seems applicable is Stakeholder Theory, first articulated by Freeman (1984) and Donaldson and Preston (1995) as a lens on strategic management, with another 25 year re-release of Freeman's book in 2010 (Freeman, 2010). In it a business can be described as a set of relationships among groups which have a stake in the activities that make up the business such as customers, suppliers, employees, financiers, communities, and managers and how they interact to create value. Therefore the definition of a stakeholder in an organisation is *"any group or individual who can affect or is affected by the achievement of the organisation's objectives"* (Freeman, 1984:46) and an entrepreneur's job is to manage and shape these relationships (Freeman *et al.*, 2010:24). They can be primary or secondary stakeholders but no stakeholder acts alone to create value and interactions between the stakeholders are interdependent and multifaceted. Sounds very similar to an ecosystem approach to me with stakeholders jointly tied to create value, without resort to trade-offs, through a purpose that is aligned amongst the key stakeholders (Freeman *et al.*, 2010:27). I have adapted his illustration of stakeholders to be consistent with those I purposively selected for 3DCP ecosystem actors to be consistent with Moore (1996). See Figure 3.2 Adaptation of Stakeholder's View Model below:



Adapted from *Strategic Management: A Stakeholder Approach* Freeman (2010:25, Fig 1.5)

Figure 3.2 Adaptation of Stakeholder's View Model (Freeman, 2010:25, Fig 1.5)

By placing stakeholder in the centre of strategic thinking, the unit of analysis is changed to a more relational view of business with the central characters as companies and the relevant stakeholders and the business works in the interests of all of these stakeholders (Freeman, 2010). It is at the intersection of these interests and interdependencies which is fundamental to effective and sustainable stakeholder management that can be seen as closely aligned to the ecosystem concept.

The stakeholder concept can then be viewed for strategic management purposes as how a corporation can and should set and implement direction to be successful, with company executives simultaneously satisfying the owners, the employees and their unions, suppliers and customers. As with ecosystems, stakeholder theory recognises the external environment as integral to a company's success and its need to construct a framework which allows managers to more effectively handle disruptive external environments (Freeman, 1984). The external change could represent the emergence of new groups, events and issues requiring a new business model or strategy. This can be seen as Moore's stages of business ecosystems with ecology used as a metaphor for the external business environment.

Consistent with my own stance, Freeman *et al.* (2010) are philosophical pragmatists around methods and theory as many conceptualisations of stakeholder theory can be

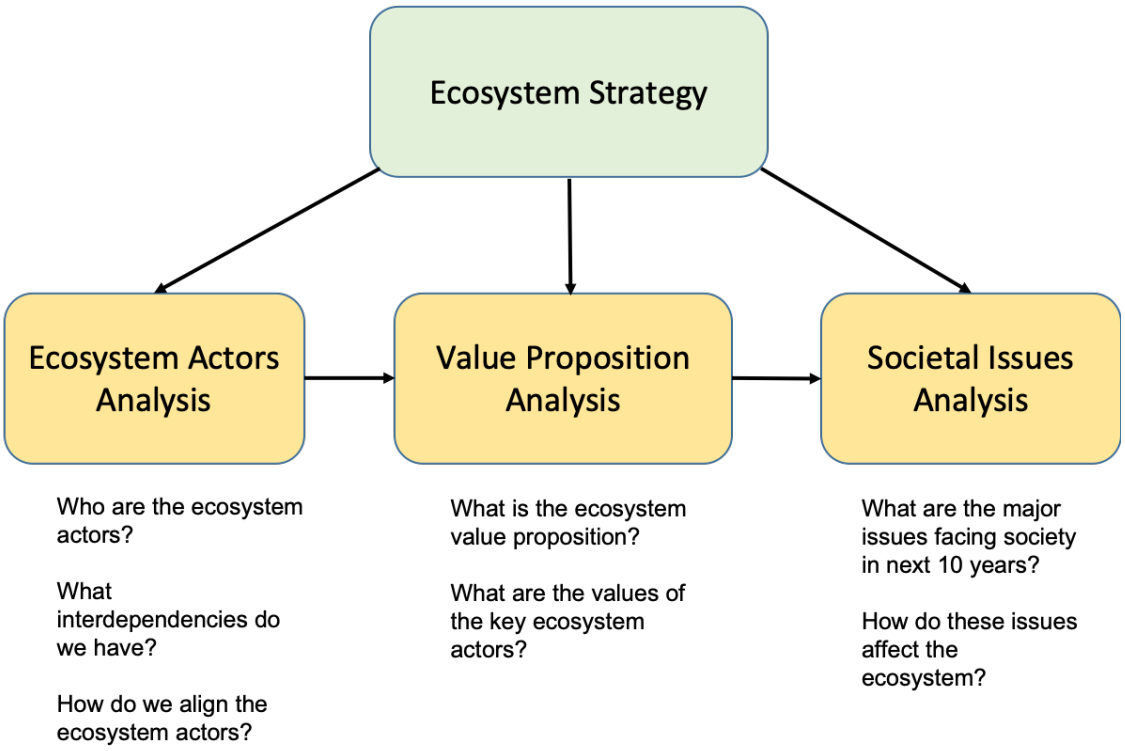
given. They believe scholars should take a pragmatic approach to multiple interpretations of a given phenomenon and should consider the virtues of multiple perspectives and evaluate their usefulness. Pragmatism sees both theory and practice as important criterions in research. Practice shows us what can be done, whilst theory pushes us to consider more radical concepts and possibilities.(Freeman *et al.*, 2010:76). So, whilst previously stakeholder theory has typically been associated with the corporate social responsibility field, it addresses many of the same visions as business ecosystem research in that stakeholders or ecosystem actors must come to take into account the effects of their actions on others in society and be aligned around a vision or value proposition. With regard to strategic management, the idea of stakeholder theory is consistent with strategy theories such as Porter's five forces and shared value (Porter, 1980; Porter & Kramer, 2006; 2011) and Williamson's transactions cost economics theory (Williamson, 1991; 2007). The stakeholder perspective is also closely related to concept of network strategies (Gulati, 1998; Ireland *et al.*, 2002; Kale *et al.*, 2002) and links to the resource focus of RDT as both believe that interest groups drive the effectiveness of organisations (Pfeffer & Salancik, 1978). A more recent conceptualisation envisages competing networks of stakeholders (Freeman *et al.*, 2010:117, Fig 4.3) as reproduced below in Figure 3.3 highlights where they can both compete and collaborate as well as share different stakeholders. This is akin to the business ecosystem model where collaboration and competition are part of the ecosystem strategy at the various stages of ecosystem development (Moore, 1993).

Figure 3.3 Competing Stakeholder Networks (Freeman et al.*, 2010:117, Fig 4.3)*

Stakeholder engagement is core to the theory as a business must engage with its stakeholders to create value and almost every business transaction involves

customers, suppliers, communities, employees, and financiers. Similar to business ecosystems, this acknowledges that a large cast of stakeholders is necessary to sustain value creation and recognises the role of many stakeholders in the value-creation by engaging stakeholders through shared value propositions to create sustainable value (Freeman *et al.*, 2010). Also, the principle of continuous creation is key for if a business is the source of the creation of value the organisation through cooperating with stakeholders and values, continuously create new sources of value. Freeman *et al.* (2010) believe it is not just Adam Smith's self-interest that is the initiation of innovation or progress. Collaboration with others and creating value for others can also be a motivation. This kind of innovation typically comes from engaging with stakeholders to generate new ideas and evaluating their new alternatives. These are all very familiar issue and challenges for those scholars engaged in business ecosystem research and the initial stakeholder strategy framework (Freeman, 1984:44) comprises of a number of key questions which can now be addressed through the business ecosystem framework: What is the direction or mission of the organisation? (Value Proposition); What strategies will achieve such a mission? (Ecosystem Strategy); What resource allocations or budgets must be made for the strategies to be implemented? (Ecosystem Actors and Complementarities); Who monitors the strategy? (Keystone Player); What are the systems and structures needed for success? (Ecosystem Type). These will all be explored in later sections as they formed part of the initial basis for the Interview Protocol (4.5.5.2 below).

A key component of ecosystems surrounds strategy. Here again stakeholder theory is relevant by adapting the Enterprise Level Strategy Process (Freeman, 1984:91, Fig 4.2), through the substitution of *Enterprise Strategy* with *Ecosystem Strategy* with corresponding adaptions to the Stakeholder Analysis (Ecosystem Actors) and Values Analysis (Value Proposition) whilst retaining the Societal Issues Analysis. This provides a clear direction to align the actors, values and positions for an ecosystem strategy framework for disruptive innovations such as BIM and 3DCP whilst staying consistent with the latest ecosystem research (Adner, 2017; Jacobides *et al.*, 2018). See Figure 3.4 for an illustration of this adaptation.



Adapted from Freeman, *Strategic Management: A Stakeholder Approach* (1984, Exhibit 4.2)

Figure 3.4 Ecosystem Strategy (Adapted from Freeman, 1984:91, E4.2)

3.6 Disruptive Innovation

3.6.1 Types of Innovation

Christensen *et al.* (2019:10) define innovation as *"a change in the processes by which an organization transforms labour, capital, materials, and information into products and services of greater value."* Innovation can be seen as the commercialisation of invention where commercialisation can be viewed as the marketing of an innovation with the aim of capturing value in the marketplace (Aarikka-Stenroos & Lehtimaki, 2014). Note the distinction between invention and innovation, as an invention is a completely new 'thing' whereas an innovation is a method that enables inventions. The iPhone is a collection of technological inventions but as an innovation the iPhone created an ecosystem of media, telecommunications and Apps under one umbrella to enable those inventions. Therefore an innovation is use of an invention or collection of inventions alongside a business model to create use from the invention (Walker, 2015). However, not all innovation should be described as disruptive. There are two general types of innovations: *discontinuous* innovations that emerge from disruptive technology whereas *continuous* innovations emerge from evolutionary technology (Walsh *et al.*, 2002). The term discontinuous innovation was widely used before disruptive

technology became popular (Anderson & Tushman, 1990). Technological discontinuity involves new processes or technologies operating in new technological domains (Aarikka-Stenroos & Lehtimaki, 2014). Therefore, the two terms, disruptive and discontinuous, are very similar but disruptive is better recognised and more tangible than discontinuous, leading to its popularity. Subsequently disruptive innovation is now preferred to disruptive technology because innovation is a wider concept encompassing business, institutional, and user-generated innovations. (Kilkki *et al.*, 2018).

Scholars have described the various types of innovation with ever greater refinements to definitions to distinguish between incremental changes in functionality and cost of production or disruptive products and services. The focus of this research is to observe how the construction industry is reacting to different types of innovations such as 3DCP and BIM and to be able to define the type of innovation they represent.

I briefly outline the main six below in order to define those which apply for this case research study:

3.6.1.1 Sustaining Innovation

Sustaining innovations describes improvements an industry creates through the introduction of new and more-advanced products or service to serve its higher end, more-sophisticated market customers (Christensen *et al.*, 2000). Therefore sustaining innovations meet the demands of existing customers in established markets (Christensen *et al.*, 2002). Sustaining innovations relate to products and services which are typically sold at a higher price for a higher margin and are generally focused on selling more products to the same customers in the same market. (Christensen *et al.*, 2019). An example would be an iPhone X superseding an iPhone 8. They exhibit a continuous improvement process to address internal and external customer problems and can be planned along an expected technological process to add benefits to the established industrial value chain (Kassicieh *et al.*, 2002). As such sustaining innovations are used by incumbents rather than disruptors.

3.6.1.2 Efficiency Innovation

Efficiency innovations allow the same product to be produced at lower cost to the company through use of fewer resources, including labour, materials or capital. (Christensen et al., 2019). Efficiency innovations are crucial for the survivability of companies in competitive, commoditised industries by enabling them to produce more with fewer resources. These are typically innovations in processes on how a product is

made. Efficiencies can increase productivity but often at the expense of workers. An efficiency innovation business strategy focuses an organisation on how to extract as much as possible from existing and newly acquired assets by selling their products into the "consumption economy," which targets those who can already afford existing products on the market. Because these innovations are not focused on the non-consumption economy, they usually do not create new markets. Both sustaining and efficiency innovations can be utilised to create a better product with less resources or with more functionality (Christensen *et al.*, 2019). However, the social returns often outweigh the private returns for firms incrementally improving technologies to solve a societal problem as they can be easily copied by second movers diluting the incentives for first movers to develop the innovation. In these circumstances governments and policy makers can play a significant role (Christensen *et al.*, 2019) as I explore in the interviews surrounding BIM innovation in construction.

3.6.1.3 Market Creating Innovation

The success of everything depends upon intuition, the capacity of seeing things in a way which afterwards proves to be true, even though it cannot be established at the moment (Schumpeter, 1934).

In effect this means that what cannot be seen by industry incumbents may prove the most lucrative to disruptors interested in discovering market creating innovations. Market creating innovations require disruptors as incumbent companies and their employees rarely see the benefits from a new market in their industry.

Market creating innovations logically create new markets. These are typically disruptive to existing markets, but not always as several new markets such as microfinance have been described as *non-disruptive creation*, which enlarges the sector without destroying existing businesses or markets (Kim & Mauborgne, 2019). These new markets either serve people for whom either no products had so far been invented or creating innovation in existing products that were previously unaffordable or inaccessible to lower- and middle-income people. Market creating innovations allow a simplified product compared to existing ones, which are cheaper and more accessible so that many more people are able to buy and use them (Christensen et al., 2019)

If a market is created, then the inference is it cannot have any existing consumers. Christensen *et al.* (2019) suggests that prosperity for many developing countries will come from investing in innovations that create new markets within those countries as these innovations act as a catalyst for creating sustained economic development. Market-creating innovations convert expensive, complex products and services into

simpler, more affordable products, making them accessible to non-consumers. Non-consumers are defined as people who are struggling to make progress due to solutions being non-existent or out of reach and therefore would benefit from the creation of a market focused on them (Christensen *et al.*, 2019:10). Market creating innovations generate jobs, profits and societal change, if a culture of innovation takes hold in a country. All three combine to create a solid foundation for future growth. These new markets serve non-consumers for whom existing products were neither affordable nor accessible or non-existent and the larger the non-consumption economy in a country, the bigger the potential market opportunity and the more substantial the benefits. It also makes sense to promote home grown innovators as evidence suggests the returns from locally developed innovations are more likely to fund future innovations in that local market. Out of the $70 trillion worth of global assets under management, only $2 trillion are found in foreign direct investments as most money stays in the domestic market (Christensen *et al.*, 2019).

Whilst sustaining and efficiency innovations keep companies and economies moving, it is the market-creating innovations where future growth is created by targeting large underserved portion of the population with solutions to improve their lives. Through the innovation a viable market targets non-consumption, usually the majority of people in a poor or developing economy, which helps create a virtuous feedback loop for jobs and economic profits to build a more developed society or nation (Christensen *et al.*, 2019). But investing in both affordability and availability is key to building a successful market-creating business but evidence suggests companies focus disproportionately on product affordability compared to product availability (Christensen *et al.*, 2019).

In summary then a *"market-creating innovation isn't simply a product or a service. It is the entire solution: the product or service coupled with a business model that is profitable to the firm."* (Christensen *et al.*, 2019:82).

3.6.1.4 Frugal Innovation

Frugal innovations, also referred to as *low-end* or *inclusive innovations*, are defined as new products or services that expand a market by addressing consumers with a low ability to pay. This type of innovation can perform a hybrid role as they can be both a criteria for firm survival and a major driver of societal change (Reinhardt *et al.*, 2018). Frugal innovation can involve multinational companies exploring new markets whereas inclusive innovation refers to the market-driven innovation processes that focus on the needs of those at the Base of the Pyramid (BoP) and which involves the BoP as consumer, producer, employee and entrepreneur. These processes result in products

and services that combine the four A's; Awareness, Accessibility, Affordability and Availability (Cañeque & Hart, 2017). This type of innovation has obvious links to the market creating innovation described above as both target the non-consumer.

3.6.1.5 Open Innovation

Open innovation can be defined as "*the pooling of knowledge for innovative purposes where the contributors have access to the inputs of others and cannot exert exclusive rights over the resultant innovation"* (Chesbrough & Appleyard, 2007:60). The concept of open innovation concerns the willingness and transparency of an organisations' approach to their innovation processes, regardless of whether they are an innovator or an innovation adopter (Chesbrough, 2006). Open source innovation typically drives rapid development and involves more players than closed source innovation within companies (Chesbrough, 2003).

Open innovation has driven down the cost of 3DP and has led to extensive use of 3DP in the automotive and aerospace industries, yet to date the construction industry has been slow to utilise this approach, although BIM is driving the sector towards greater openness and collaboration. Open source software and file sharing allow worldwide collaboration on building design implying Additive Manufacturing has the potential to democratise building design (Labonnote *et al.*, 2016). Small manufacturers and DIY builders can benefit from projects, such as WikiHouse, which embrace an open source building system through collaboration to develop the "*best, simplest, most sustainable, high-performance building technologies, which anyone can use and improve*"(WikiHouse, 2020). Open innovative construction technologies could pave the way towards a future of sustainable construction, reduce construction and facilities management costs, reduce environmental impact and improve safety for workers (Tay *et al.*, 2017).

Open innovation collectively refers to strategies including open innovation, crowdsourcing and collective intelligence (Altman & Tushman, 2017). Platforms, open innovation, and ecosystems represent three closely related or overlapping strategies where players can create and capture value. All three strategies describe interactions where organisations interact with and obtain value from other organisations outside their boundaries. Opportunities and challenges related to openness, interdependence, and co-opetition arise as organisations interact with players outside their boundaries (Altman & Tushman, 2017). Adner (2017) argues that there is a distinction to the ecosystem concept as open innovation relates more to a firm's governance of its internal processes whereas in an ecosystem the question of multilateral coordination

lies outside its scope. Therefore, to consider whether open innovation acts as a bridge between ecosystems and disruptive innovation led me to ask participants about their open/closed approach.

3.6.1.6 Business Model Innovation

A business model *"depicts the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities."* (Amit & Zott, 2001:493) and represents the "*design or architecture of the value creation, delivery, and capture mechanisms"* of an organization (Teece, 2010:172). Business Model Innovation *"enable innovators to capture a large enough portion of the (social) value generated by innovation"* (Teece, 2007:1331) with the business model potentially the source of value creation for the firm and other actors in its external environment (ecosystem), if correctly chosen (Amit & Zott, 2001). As the business model consists of interdependent activities performed by an company and its partners and the mechanisms that link those activities, it is the template that represents how a firm conducts its business to meet the perceived needs of its customers (Zott *et al.*, 2011). As an analytical concept the business model is therefore nestled between the firm's internal capabilities and its network (ecosystem). Whilst centred on a focal firm it extends beyond the firm's boundaries by including interactions with other stakeholders to create and capture value. It helps to conduct multilevel research and to integrate theoretical perspectives through the business model as unit of analysis (Amit & Zott, 2001)

In a similar approach to ecosystem literature, a business model framework comprises three components: (1) Value proposition (the value to its customers) (2) Value creation (how is value created); and (3) Value capture (how the company captures value) (Tongur & Engwall, 2014) which neatly brings the ecosystems and business model areas together.

However new ventures using a disruptive innovation through their ecosystem has led to renewed focus on how that innovation interacts with a company's business model. Disruptive business models has been defined as "*business models that disrupt an established model or redefine what value creation and capture mean"* (Cozzolino *et al.*, 2018:7). This general definition for business model innovation as the *"search for new logics of the firm and new ways to create and capture value"* (Casadesus-Masanell & Zhu, 2013:464) implies a dynamic process of rebirth of the whole concept of value, to a firm and the broader society through innovation, although for incumbents the term business model adaptation may be more appropriate. In this case an incumbent firm

adapts its existing business model rather than to invent it from scratch (Cozzolino *et al.*, 2018). Disruptive new business models for new ventures include new partners and activities configured in novel ways in comparison to incumbents (Amit & Zott, 2012).

An *open business model* or strategy combines open innovation and business model innovation for firms who need access to external knowledge sources as well as an open approach to intellectual property rights alongside the use of tools and services (often via a platform) whilst incurring lower costs for platform provider and users (Cozzolino *et al.*, 2018). In an example of how a new business model can work Christensen *et al.* (2019) discussed how America embraced the innovation model with industry giants like Singer, Eastman and Ford deviated from industry norms to develop new business models that targeted the non-consumer. Singer developed a hire purchase business model to allow expensive sewing machines to be bought by lower income families, Eastman developed a business model that focused on four main principles: the customer, mass production at low cost, worldwide distribution, and mass advertising whilst Ford envisioned a car for the multitudes, constructed from the best materials with a simple design that was so low in price that any good salaryman could afford it. In effect they all targeted an underserved market, the non-consumer. These are the large swathes of the population, especially in poor or developing countries that are currently shut out of consuming existing products due to affordability or availability issues. To target the non-consumption economy requires local knowledge as well as technical knowledge of how to efficiently make and ship a product. If done successfully it can create a vibrant market to generate jobs, help develop the nations regulatory and institutional framework and have spill over effects into other adjacent industries in the local economy. By targeting non-consumption scaling becomes inexpensive (Christensen *et al.*, 2019).

The business model choice for an innovative company is crucial as innovators are often not rewarded from their new products or services, as much as imitators, customers and other participants (Teece, 1986). A fast second or third entrant into a new market can capture more value than a first mover. Start-ups that proactively pursue new market opportunities tend to be first movers in disrupting established players with new products (Christensen, 1997). However, small innovative firms are less likely to have specialised or co-specialised assets within the firm's boundaries. Therefore innovators who do not have access to these assets need to have strategic partners or they will lose value capture to imitators (Teece, 1986)

Business models are distinct from ecosystems as they showcase an individual company's plan to create and capture value. Therefore, unlike an ecosystem the focus is on the firm itself, not a collection of actors in the same sphere. The unit of analysis is

the firm's individual strategy not a value proposition for a wider group of collaborating players (Adner, 2017). A business model can extend across different geographical regions whilst the ecosystem value proposition may be bounded by the collection of players in that particular ecosystem and the strategy to deliver that ecosystem's value proposition.

Business strategy and business model have not been clearly differentiated with some scholars referring to platforms, open/user innovation, and ecosystems as business strategies when others might prefer defining them as business models (Altman & Tushman, 2017). Linking business model to business ecosystem, a business model is the outcome of a group of relevant activities of a company, which occur and evolve out of the ecosystem in which the company operates. Whereas a business ecosystem forms the context in which a business model evolves (Rong *et al.*, 2018). Brennan (2015) reframed Moore's collective value creation theory by portraying a business ecosystem as consisting of multiple business models, rather than a single business model which envisions individual and collective value creation. The "disruptor's gambit," where the disruptor reveals its intentions early on using effective framing then rapid adaptation of its business model to satisfy its ecosystem through this iterative framing and adaptation process to move the ecosystem evolution from incumbent to disruptor centred (Snihur *et al.*, 2018).

From the descriptions above, it is apparent that there are multiple types of innovation covering products, processes and business models. There are overlaps as well as distinctions between types of innovation.

Sustaining and efficiency innovations are ubiquitous in all industries as companies use the current business models to stay competitive against known rivals. Market creating innovations are scarce, require more effort to gain traction but ultimately provide the greatest value creation provided the internal and external environment are conducive. Frugal innovations can be any of the three above, with the target audience the key differentiator.

The strategies and degree of openness and innovativeness for the configuration of the internal business model are important components to introduce any type of innovation. However, a company must first decide the innovations it is facing are disruptive.

3.6.2 Definition of Disruptive Innovation

The overuse of the term *disruptive* has led to many writers labelling any new technology or innovation that aims to shake up an industry and alter its competitive

patterns as disruptive and any previously successful incumbents facing difficulties or going out of business are now routinely said to have been disrupted (Christensen *et al.*, 2018). As described above innovations take many forms and researchers and practitioners must analyse what is really disruptive and/or what has been disrupted when discussing innovation. I have specifically researched this point with the participants in this study and I have reviewed the different types of innovation in the literature to focus only on those which I consider as disruptive.

Since the publication of his seminal book, *The Innovators Dilemma* (Christensen, 1997), many authors have tried to define the scope of both disruptive technology and disruptive innovation (Adner, 2002; Christensen *et al.*, 2015; Danneels, 2004). Christensen *et al.* (2015:46) have provided a succinct definition with disruption described as a *"process whereby a company with fewer resources is able to successfully challenge established incumbent businesses. Specifically, as incumbents focus on improving their products and services for their most demanding (and usually most profitable) customers, they exceed the needs of some segments and ignore the needs of others. Entrants that prove disruptive begin by successfully targeting those overlooked segments, gaining a foothold by delivering more-suitable functionality—frequently at a lower price. Incumbents, chasing higher profitability in more-demanding segments, tend not to respond vigorously. Entrants then move upmarket, delivering the performance that incumbents' mainstream customers require, while preserving the advantages that drove their early success. When mainstream customers start adopting the entrants' offerings in volume, disruption has occurred."* See Figure 3.5 Disruptive Innovation (Adapted from Christensen, 1997) for a graphical adaptation of this definition:

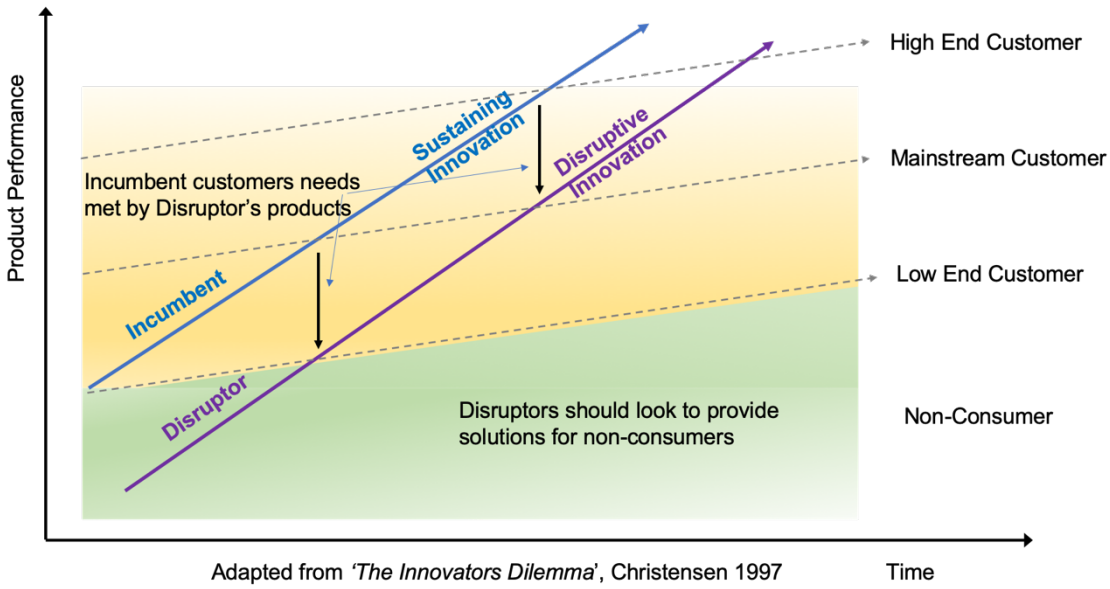


Figure 3.5 Disruptive Innovation (Adapted from Christensen, 1997)

Initially Christensen described the technology as disruptive through his research relating to the disk drive industry but this has subsequently been widened to include other innovations that *enables* the technology implying the disruption can be considered as a process rather than a technology (Christensen & Raynor, 2003). To create the disruption within a sector companies should consider business model innovation that allows the adoption of the technology and therefore participants needs to understand the evolution of business at a market or industry level (Johnson *et al.*, 2008). This has significantly widened the research field and whilst some researchers describe the technology and others the process or business model, these all still fall under the disruptive innovation umbrella. As Christensen has moved away from the actual technology and towards the process and business model that enables that technology to capture value, so other associated fields have been drawn in including networks, ecosystems and business models.

Therefore, disruptive technologies break through the present product or technology capabilities and evolve a new competitive paradigm. These discontinuous innovations can be products, services or processes that deliver substantial improvements in value for the customer (Kassicieh *et al.*, 2002). They develop new markets or add new functionalities in established sectors, which often results in the disruption of existing markets (Yu & Hang, 2010). These new market disruptions create a new value network, where the target customer is initially the non-consumer, not the prevailing ones (Christensen, 1997). But as not all new technologies can be considered as disruptive, defined here as revolutionary, breakthrough or emergent as opposed to

those which are evolutionary or incremental (Yu & Hang, 2010). And what is being disrupted? The industry, the incumbents in that industry or society at large? These are some of the questions that scholars have sought to answer.

Yu and Hang (2010:439) define a disruptive innovation along three criteria (1) disruption is a relative phenomenon (disruption to some companies will not be disruption to another); (2) disruptive innovation does not always imply that incumbents will be displaced by entrants or emerging business and disruptors are not necessarily new ventures; (3) disruptive innovation does not equal destructive innovation as an innovation with greater performance but relatively low-cost structure would be more destructive than a normal disruptive innovation that focuses on low cost through initially lower performance. Christensen *et al.* (2015) have also elaborated on what is and what isn't disruptive with a disruptive innovation containing the following attributes: It is a process not a product or service that starts at the fringe of an industry and moves towards the mainstream; it starts at the low end to capture non-consumers or creates a totally new market; the new ventures do not reach existing customers until the quality matches their standards; not all incumbents are displaced as many disruptors fail; and the business model employed by the disruptor can differ widely from an incumbent.

Cheng *et al.* (2017) consider that a disruptive innovation employs an emerging technology to divert from the existing technology's trajectory with two approaches to either focus on quality and cost (the product) or focus on the market's characteristics (the process). Concomitantly, the disruptive innovation should alter the performance metrics or consumer expectations of a market or industry sector by introducing new functionality, discontinuous technical standards, or new forms of ownership (Nagy *et al.*, 2016).

The magnitude of a disruptive technology can also be explored, with a first order disruption represents a localised change, within a market or industry, whilst a larger second order disruption see a wider societal impact. A first order disruptive technology can come from a new venture or new entrant to a market, or from an incumbent firm. In this scenario it is the disruption to an existing market that identifies a first order disruptive technology, regardless of where the disruption comes from and are localised disruptions to a particular market or industry. A second order disruption touches many industries where the disruptions ripple through society, creating large scale sectorial and societal change. Second order technological disruptions are built off of smaller, localised, first order disruptive technologies and through a *clustering* of technologies, that come together at a particular space and time, where these disruptive innovations create new markets and opportunities through these new technologies, resulting in societal change (Schuelke-Leech, 2018)

In summary three distinct areas of change help to define disruptive innovation and technologies: (1) Change in technology or product model, which impacts the organisation's decision to commercialise a certain product; (2) Change in market structures resulting in different suppliers in the market and changing behaviours of the incumbent suppliers; (3) Change in customer benefits as adopters change their behaviour and perceptions to benefit from the innovation (Kassicieh *et al.*, 2002). To which we can add that the disruption can be localised or societal. In this research I have investigated small new ventures bringing innovation to a large globally important industry, as well as an innovation focused on a wider proposition, to observe both types of disruption impacts.

Therefore whilst I defer to Christensen *et al.* (2015:46) for the general definition of Disruptive Innovation, it may not just be low level entrants into a market that provides the disruption, and the magnitude of the disruption needs to be considered due to their entry. I have chosen BIM and 3DCP to represent different innovations to observe which type of innovation they represent and whether they fit into the definition of disruptive innovation or non-disruptive creation.

3.7 Innovation and Ecosystems

An ecosystem can be the platform for a disruption (Kilkki *et al.*, 2018). The process of disruptive innovation and the creation of an ecosystem both come under the umbrella of strategy. A firm in an ecosystem can be the disruptor, the disruptee or a neutral observer if the disruption does not affect them directly. In an ecosystem, a majority of players may stay passive without expectations or intentions. Incumbent organisations are forced to change strategy or innovate when a disruptor enters their sector, in order to survive. Moore (1993) used an ecology analogy to describe how in an established ecosystem the dominant players may lose their leadership and new ecosystems then establish themselves, often with previously marginal firms and technologies at the centre, as the previous ecosystem incumbents are displaced. When those incumbent firms are facing innovation in their sector, there are clear parallels and implications that connect to disruptive innovation theory as initially the innovation may seem inferior to the established product but may appeal to a non-consumer which creates a competing emerging ecosystem from interested players (Christensen, 1997). The emergent business ecosystem collects an initial combination of capital, customer interest, and entrepreneurs to coalesce around the new innovation or value proposition (Jacobides *et al.*, 2018; Moore, 1993). During the birth stage of this nascent ecosystem, entrepreneurs constantly iterate and refine their customer value proposition with those

who best define and implement this customer value proposition initially succeeding in establishing themselves. They develop their internal and external environment through co-operation to deliver maximum value to customers whilst trying to avoid competing with an existing ecosystem (Moore, 1993).

Similarly, Christensen and Raynor (2003) devote a chapter on interdependence and modularity as a solution to creating value from innovation. They discuss what activities a firm should develop internally, and which should be outsourced to a supplier or partner. In effect this links to ecosystem strategy and business model innovation to take a new technology to the mass market. Recent articles have therefore begun to explore the crossover between disruptive innovations and the ecosystem environment they faced, as in the TiVo digital disruption of the US TV ecosystem (Ansari *et al.*, 2016) or the emergence of a new ecosystem for innovators in the residential solar industry (Hannah & Eisenhardt, 2017; Overholm, 2015). To bring their innovation to market companies, whether new ventures or incumbents, must decide the strategy and sequence for the emergent ecosystem: Start with the smallest configuration of elements that can be brought together to create the value proposition then add pieces that benefit from the existing system whilst increasing the value creation potential and then finally leveraging any innovations from one ecosystem to enable other ecosystems to develop (Adner, 2012).

The concept of a value network for innovation as *"the context within which a firm identifies and responds to customer's needs, solves problems, procures input, reacts to competitors, and strives for profit"* (Christensen, 1997:876) also has similarities to an ecosystem approach, although value networks do not explain the evolution of the network and how roles of the actors affect value creation and capture, which have been addressed in ecosystems (Adner, 2017). Within a value network each firm's competitive strategy and choice of markets determines the economic value of a new technology, shaping the return a company expects from a sustaining or disruptive technology. Typically, incumbents focus resources on sustaining technologies allowing innovators to come in and disrupt and displace them. Whilst technology S curves are often used to predict whether an emerging technology will displace an established one, Christensen states that disruptive technology follows a different uniquely defined trajectory and only sustaining technologies will follow a traditional S curve (Christensen, 1997). More recent work by Adner and Kapoor (2016a) has extended this to examine how incumbents can defend their market share by extending the existing technology or limit the pace of a new innovation reaching the market, in a reflection on both innovation and ecosystems.

Therefore taking the key attributes from Christensen (1997) and Moore (1993), I can develop an illustration that connects the two theories through strategies to capture value from an innovation at the various stages of its development and the adoption of that innovation in the market place. See Figure 3.6 below:

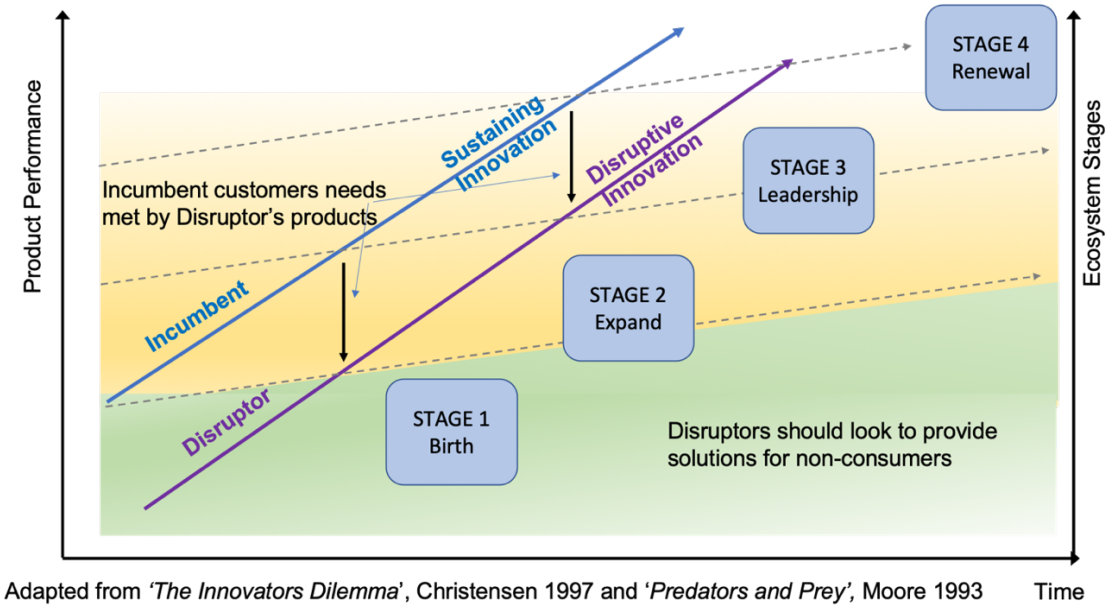


Figure 3.6 Combining Christensen and Moore: Steps to Innovation Ecosystems

At this stage however, it is still undetermined whether the focal innovation is of sustaining and efficiency type or a truly disruptive innovation. Existing ecosystems may change leaders due to incremental improvements in technology or entirely new ecosystems and value propositions may emerge from a disruptive technology. Therefore to disrupt a sector thorough innovation implies a reconfiguration of the existing ecosystem with innovative companies requiring an *ecosystem strategy* to attract complementary components as well as their new technology (Adner, 2012). Disruptors establishing their innovation ecosystem depend on the ability and alignment of all ecosystem actors to focus around a value proposition, as even the most brilliant single innovation cannot be successful, when to create and capture value depends on other innovations that must be co-created concurrently (Adner, 2012).

Ecosystem strategy differs from typical models of strategy which focus on internal competencies, firm capabilities and business models because ecosystems focus on the relationship between the firm's internal and external ecosystem (Iansiti & Levien, 2004a). This brings the wider concepts of business model and process innovation to interlink with the ecosystem. Each player leverages the network of interactions in the system to its advantage and these relationships lead to a common fate either through a

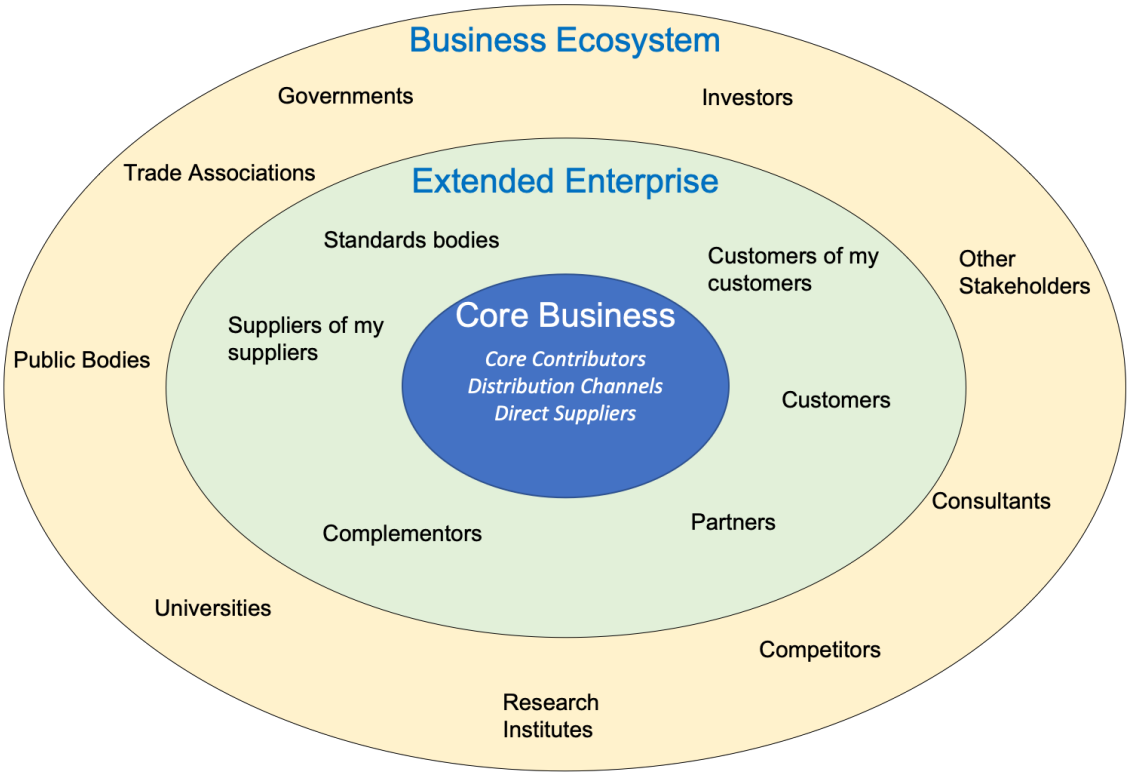
mutual benefit or mutual failure. Whilst a company may have a great product or new innovation, failing to expand their focus to include the entire ecosystem will set them up for failure as there are three risks that arise within ecosystems to successfully bring an innovation to market: (1) Execution risk: How to bring your innovation to market to specification and on time; (2) Co-innovation Risk, to what extent is the success of your innovation dependent on the successful commercialisation of other innovations; and (3) Adoption Chain Risk, for end customers to see the value proposition to what extent will partners need to adopt your innovation (Adner, 2012:413). Therefore, alongside a vision of the value that your innovation will create and who this value will be created for, innovators must still view their environment as a complex network or a hierarchy of networks with internal and external ecosystems inside and outside the boundaries of the firm yet contain common characteristics across both of them (Adner, 2012).

The innovator also needs to consider its role in the business network or ecosystem it finds itself in or is targeting as part of its business model strategy. Complex systems theory suggests that networks possess keystone players or hubs that provide network stability and enhance efficiency (Iansiti & Levien, 2004a). These keystone players can fulfil an enormously important role in the collective performance of a network. The networked and distributed structure is a relatively recent phenomenon in many industries with the critical importance of shared fate requiring a new framework for thinking about industry health and indeed about what constitutes an industry (Iansiti & Levien, 2004a). So disruptive innovators need to consider more than just their disruptive innovative product or process, they need to consider the whole concept of the disruption they wish to bring. How innovations become established in the construction sector will depend on the initial innovation and the wider ecosystem vision and strategy. Disruptors need to be able to convince incumbents in the existing ecosystem of the need to change (Ansari *et al.*, 2016) and then find strategies that innovate the wide business model or the whole manufacturing process (D'Aveni, 2018). Therefore, this research is aimed at the confluent point between disruptive innovation, the internal business model choice and the external ecosystem facing companies bringing innovation to the construction industry.

3.8 Business Ecosystems

3.8.1 Definition of a Business Ecosystem

It was James Moore (1993:76) who first applied the ecosystem concept to business where *"companies co-evolve capabilities around a new innovation: they work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations".* He surmised that an ecological approach can be used to analyse the evolution of any major business. Ecology represents the branch of biology that studies the relationships between living organisms (including humans) and their physical environment. These interactions are important since all organisms rely upon interactions with other individuals for feeding, reproducing or for being protected (Fontaine et al., 2011). An *ecosystem* is a complex network or interconnected system which considers the whole complex of not only the living organisms but also their special environment (consisting of non-living components such as sunlight, soil, water), with which they form one physical system (Tansley, 1935:299). Moore (1996:26) subsequently refined his definition to include a wider set of actors and considered the roles that they play to deliver that value proposition, as an "*economic community supported by a foundation of interacting organizations and individuals, the organisms of the business world. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organism also includes suppliers, lead producers, competitors, and other stakeholders. Over time, they co-evolve their capabilities and roles, and tend to align themselves with the direction set by one or more central companies. Those companies holding leadership roles may change over time, but the function of ecosystem leader is valued by the community because it enables members to move toward shared visions to align their investments, and to find mutually supportive roles.*" See Figure 3.7 below for a graphical illustration of an ecosystem, adapted from Moore's book *The Death of Competition* (Moore, 1996:26, Fig 2.1) which shows the core business at the centre of activity.



Adapted from The Death of Competition (Moore 1996:26, Fig 2.1)

Figure 3.7 Business Ecosystem

More recently scholars have condensed the definition for ecosystems as "*the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize"* (Adner, 2017:40). Innovative enterprises need a diverse set of partners to combine the necessary resources, both tangible and intangible, to succeed. These groups of firms collectively live in an ecosystem to launch products or services that together comprise a coherent solution and value proposition, to both customers and the involved enterprises (Adner, 2017). As small innovative firms are less likely to have specialised or co-specialised assets within the firm's boundaries so they require strategic partners or they will lose value capture to imitators (Teece, 1986; Teece, 2018b).

However, ecosystems can have contrasting characteristics depending on the structure of the interdependent activities underlying the customer value proposition, with distinctive aspects of ecosystem strategy for each one. The "*ecosystem-as-structure*" approach, assumes an activity-centric view of interdependence (i.e. a common value proposition determines the activity of the actors) whilst the "*ecosystem-as-affiliation*" approach focuses on the actor-centric (keystone player or platform) where the emphasis is on increasing the number of affiliates to that central firm, such as in the Microsoft Xbox or Apple/iTunes ecosystem (Adner, 2017). In summary whilst there are

various characteristics and traits which can differ from ecosystem to ecosystem, focus is always surrounding participants with a shared vision *and "like the idea of democracy galvanizing a society, the idea of a business ecosystem provides a vision and proof of concept that multiple contributors with differing interests can join in common cause"* (Moore, 2006:55).

3.8.2 Nested Ecosystems

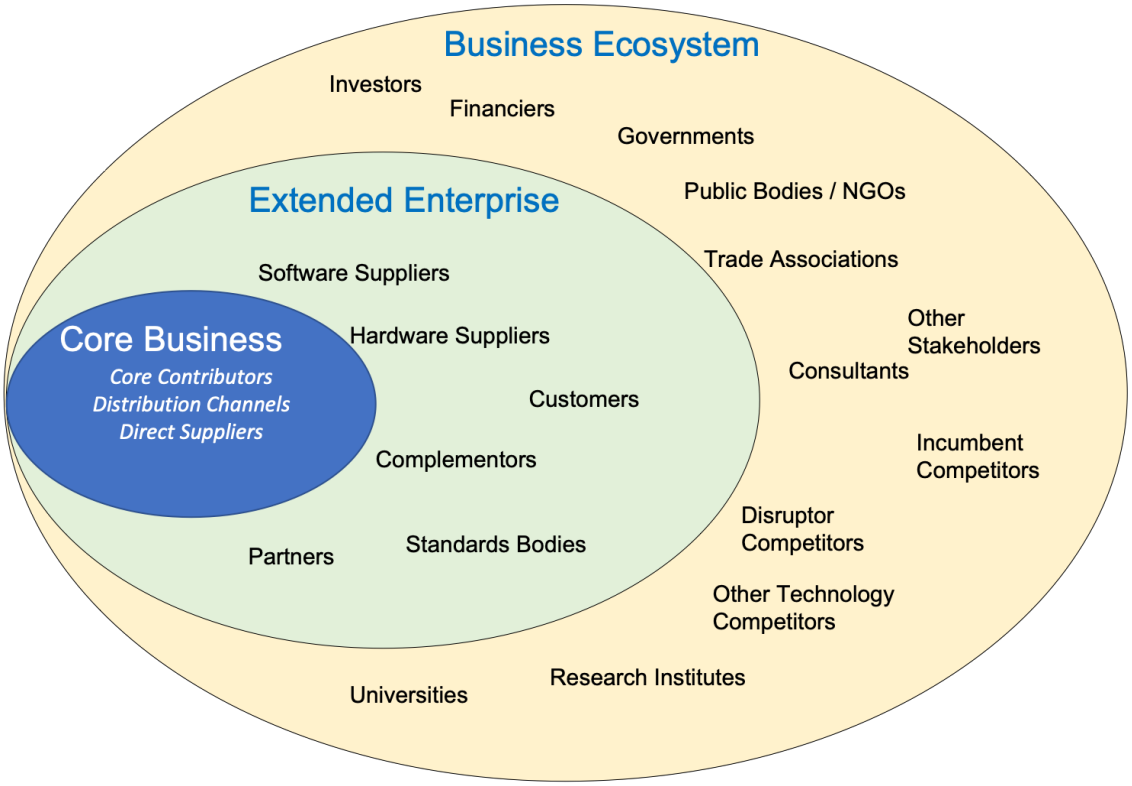
As shown in Figure 3.7 above, ecosystems have various layers with the core business as the most structured elements surrounding a company, the extended enterprise comprising highly interdependent business actors vital for survival and the business ecosystem critical but with more potentially distant players such as regulators and policymakers. As described above, ecosystems are considered to be networks of actors contributing to joint value creation where the actors, both business or non-business actors, undertaking some degree of co-innovation in order to contribute to the collective creation of value (Overholm, 2015). Some authors define a keystone player as a central actor to an ecosystem surrounded by a large number of loosely interconnected players dependent on one another for their mutual survival and success (Iansiti & Levien, 2004a:242). One aspect of biological networks is that all players are not homogenous, with richly connected hubs observable. These hubs take the form of larger keystones who serve as regulators of ecosystem health. Almost all of these systems see a keystone either a pioneer firm or through universally agreed protocols and visions.

Overholm (2015) analysed the ecosystem concept through an opportunity lens of both pioneers and followers. A pioneer firm achieved sustainable value creation only through an innovative or new business model as the founders were not in a position to imitate any significant part of a competitor's pre-existing business model. Whereas followers based large parts of their business model on pre-existing companies, including the pioneers in new ecosystems.

A unique attribute of ecosystems is the trend towards standardised interdependencies for each role, demanding a new skillset when designing the ecosystem (Helfat & Raubitschek, 2018). As the strength of ecosystems is the provision of a structure within which a group of actors with multilateral, non-generic complementarities, either production and/or consumption, firms must consider how can they be enclosed and coordinated without vertical integration (Jacobides *et al.*, 2018). It is through these interdependencies and roles that ecosystems collect various technologies and complementarities which enable the value proposition or innovation to be successful

(Adner *et al.*, 2013) but they have varying connection strength, which relates back to Adner (2017) and the strategies of structure or affiliation.

To better illustrate this Moore's original graphic can be reconfigured to showcase potentially more distance from the centre as well as degrees of separation from the core business, with either direct or indirect links between the nested layers of the ecosystem, to view the ecosystem construct through a complexity science lens of non-linear networks and connections (Russell & Smorodinskaya, 2018). For this research, Figure 3.8 illustrates the players of an ecosystem and the ecosystem layers which has been used to identify required participants.



Adapted from 'The Death of Competition' (Moore 1996:26, Fig 2.1)

Figure 3.8 Nested Ecosystem Layers

3.8.3 Ecosystem as a Complex Network

Various research has sought to distinguish between ecosystems and other relationships such as alliances, networks and other keywords including partnerships, coalitions, inter-organisational relationships, collaborative agreements and clusters (Adner, 2017; Dedehayir *et al.*, 2018; Ozcan & Eisenhardt, 2009; Provan *et al.*, 2007). Emergent research has started to investigate the similarities and differences between ecosystems and networks (Shipilov & Gawer, 2020). Whilst both ecosystem and

network theory examine how organisations manage dependencies with the external environment, there are variances based on the level of hierarchical control. Building on the work of Jacobides *et al.* (2018:2264) who described ecosystems as *"a set of actors with varying degrees of multilateral non-generic complementarities that are not hierarchically controlled,"* Shipilov and Gawer (2020) contrast this to alliances and business networks, which usually involve formal interorganisational relationships. They explore the strength and structure of these complementarities to measure ecosystems through the strengths of interdependencies between components, the extent to which these have an integrated or hub and spoke nature and use the concept of network centrality to conceptualise bottlenecks (Shipilov & Gawer, 2020). I also believe that the connections and complementarities seen in both ecosystems and networks needs further investigation.

Networks have been heavily studied in other scientific fields such as biology, physics and computer science (Barabasi, 2014; Boccaletti *et al.*, 2006; Fontaine *et al.*, 2011). Indeed Barabasi and his peers have been instrumental in the growth of network theory over the past 20 years and his recent book '*Linked - How Everything is Connected to Everything Else and what it Means For Business, Science and Everyday Life*' (Barabasi, 2014) explores networks from a range of scientific disciplines, including business. Network theory is a form of graph theory where mathematical structures are used to model relationships between objects. It is strange that more crossover analysis has not appeared on business ecosystems especially as platform ecosystems very much resemble *directed networks* or *social networks* whilst innovation systems closely resemble *hybrid* or *mesh networks*. Business networks are still poorly understood and most often poorly managed. Nascent ecosystems can potentially disrupt incumbent companies and create opportunities for new innovative company growth, network effects can generate enormous value for the ecosystem players and large barriers to entry to those not involved (Iansiti & Levien, 2004a). Of the papers analysed for this review, very few use network theories either for or against the concept of ecosystems. Whether this is due to academics staying within their fields with 'silo' thinking or whether Shipilov and Gawer (2020) are correct is seeing alliances out of fashion whilst ecosystems is hot is debatable.

Characteristics of a network include the *degree of centralisation*, with highly centralised consisting of a few firms with direct links to most others in the network, *degree of linearity* in regards to a value chain, *density* measured by the number of redundant ties relative to network size and *structural holes*, ties in the network that bridge two otherwise unconnected sections of the network (Burt, 1992). A key benefit of a network is access to advice, information and problem solving, both in the start-up phase and in

later stages of development (Hoang & Antoncic, 2003). In summary, how a network is structured relates to the direct and indirect ties between actors, with their positioning within the network determining resource flows.

A network has be defined as *"a group of three or more organisations connected in ways that facilitate achievement of a common goal"* (Provan *et al.*, 2007:482) or "*a set of actors and some set of relationships that link them"* (Hoang & Antoncic, 2003:167). However, both these definitions sound similar to that of an ecosystem. The smallest network is a connection between only two companies a strategic alliance, represented by two nodes on a network. Strategic alliances form when firms recognise they are in a vulnerable strategic position, especially when in emergent industries or attempting new technology strategies (Eisenhardt & Schoonhoven, 1996). Therefore, I was cognisant of whether I was observing alliances rather than a wider ecosystem strategy when interviewing participants for new innovations in construction. Strategic alliances are usually a tighter form of network involving cooperative arrangements for a collaborative advantage (Shipilov & Gawer, 2020). These alliances can strengthen participating firms by providing materials, skills and capital resources whilst allowing them to share development and marketing costs (Hamel *et al.*, 1989). Therefore firms enter into a single strategic alliance for a variety of reasons including governance, evolution and performance (Gulati, 1998) but as strategic alliances are ubiquitous in the business world, many firms are interested in building a number or portfolio of alliances to create value for the firm (Lavie, 2007; Ozcan & Eisenhardt, 2009). Using resource dependency and social network theoretical lenses offers an explanation of portfolio formation when interdependent firms accumulate further ties to become more embedded in a network influenced by the initial set of firm resources and its initial alliances (Ozcan & Eisenhardt, 2009). This is very similar to the ecosystem strategy a firm adopts at the birth stage and builds on the antecedent theories I described above.

Also relevant as a bridge between alliances/networks and ecosystems is how firm's assess the internal environment of a potential partner firm so that alliances are formed to achieve what it alone cannot (Das & Teng, 2000a). Pooling of resources achieves substantial benefits for the alliance partners through the value creating collection of combined resources. Observations on Korean technological start-ups (Lee *et al.*, 2001) finds that an assessment of internal capabilities and use of social network for external capabilities leads to better firm performance. Successful companies understand that the important aspect of an alliance is the chance to learn from their partners and better understand their partner's range of capabilities to allow them to compete more successfully (Hamel *et al.*, 1989). Successful alliances sees top management forge

stronger partnerships between firms through strong social connections (social networks) based on reputation, status or trust (Eisenhardt & Schoonhoven, 1996).

Therefore, alliances may start with the two nodes then morph into larger networks culminating in vast social or complex networks and platforms using *'network effects'* (Gawer & Cusumano, 2014) to create scale free networks (Barabasi, 2014). This network effect connects isolated clusters of nodes into a giant cluster, with the potential to join almost everyone to a world spanning social net, from which no one is left out. Whilst we do not know everybody in the world, it is guaranteed that there is a path between any two of us in this web of people. Likewise, there is a path between any two companies in the world. Only one link is required to stay connected or one link to trade with at least one other company in the business world. It is estimate that individuals each know between 200 and 5,000 people whereas an individual company can be linked to hundreds, thousands or millions of suppliers and customers (Barabasi, 2014:363). These dynamic complex networks can be considered as an ecosystem.

Network topologies are frequently employed in computer science describe how IT systems are connected together, from simple bus networks to fully connected networks (DNSstuff, 2019). In ecology studies, from which Moore (1993) first conceptualised a business ecosystem, researchers are now considering the implication of merging different types of networks through nested and sub networks, where they recognise the patterns and processes observed through networks, to improve their understanding of biological communities (Fontaine *et al.*, 2011). And the advances in computer power has caused a surge in research into complex networks (Boccaletti *et al.*, 2006) that cover everything from the internet to neural networks through to virus propagation. Considering that the dictionary definition of an ecosystem is a "*complex network or interconnected system*" (OED, 2010) it seems that further work needs to be carried out in this area for ecosystems. I have reviewed the various types of network observed in industry and illustrate the main ones in Figure 3.9 below. As can be seen from the diagrams, simple constructs such as bus and star networks can be joined to form hybrids. In relation to companies and ecosystems, a small firm can be described as *fully connected* with a few people interacting with all other employees, through to a typical hierarchical *tree network* structure typically seen in larger companies. For graphical illustration of ecosystems, these can be centralised or decentralised, with one or multiple keystone players or a platform leader.

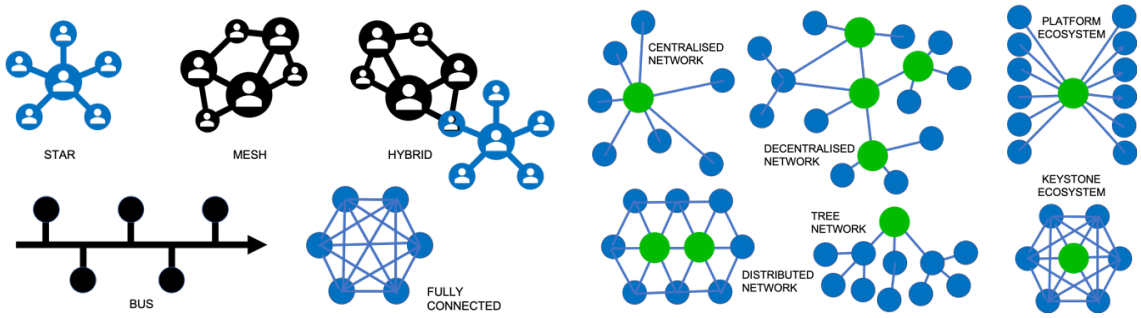


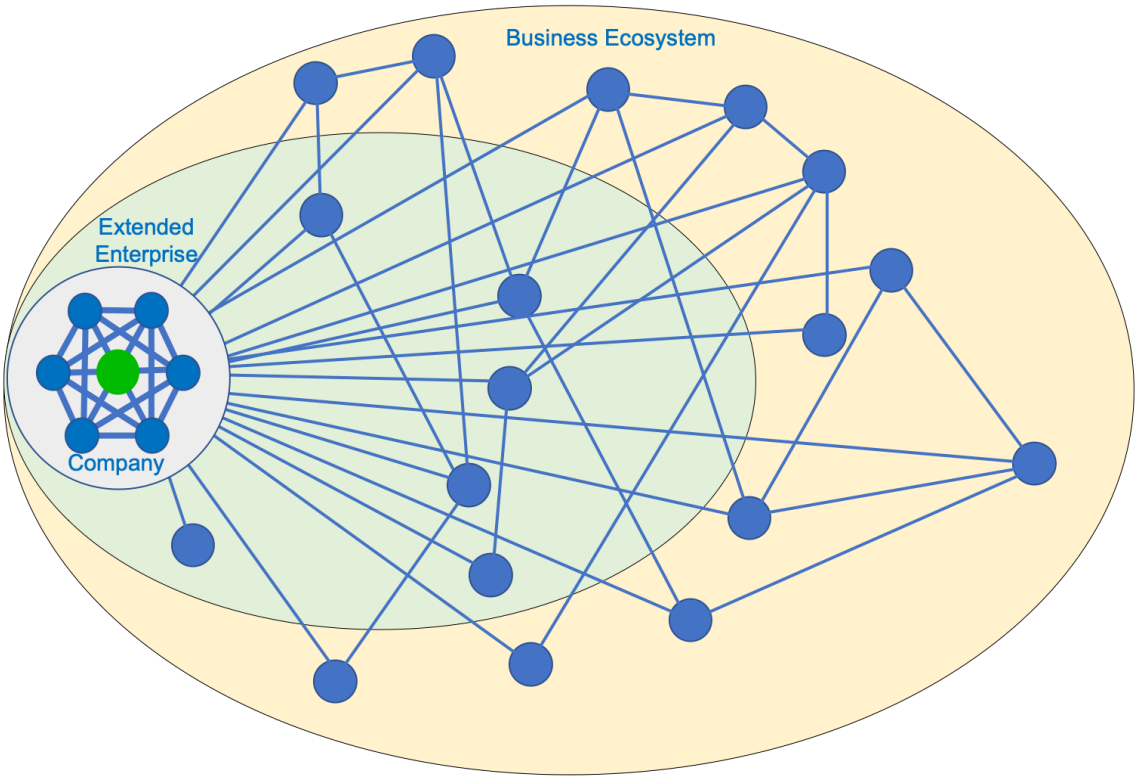
Figure 3.9 Network Topologies

Therefore, business networks can be seen as a nested, hierarchical system of manufacturers and markets, with a corresponding nested hierarchy of components, products and systems (Christensen, 1997; Dedehayir *et al.*, 2018). Network approaches focus on connectivity between actors, either through an individuals' social network or a firm's network of alliances. As opposed to ecosystems, networks do not prioritise a value proposition, as although firms may form partnerships with the same firms repeatedly, they may encounter different ecosystems with different actors and different challenges for each new product or service. For example, Apple may work with Microsoft in interactions on a new chip design but Microsoft's ties with Apple when aligned on game card processors will involve different actors and different challenges. These can be seen as two distinct ecosystems (game card, chip) with different objectives yet involve the same network of technology companies (Adner, 2017).

Social network theory (Burt, 1992) implies that a firm's external network of suppliers and partners can help reduce its cost to manufacture new products and create value for customers. New technology firms such as 3D construction printer manufacturers or BIM software providers need to build up a network with firms holding beneficial assets and resources to succeed but can do this through a value proposition in an ecosystem or through a network or strategic alliance. But as firms forge collective strategies with other complementary resourced firms, the boundaries between organisations, networks and ecosystems can become blurred (Afuah, 2003). This highlights why further research into the similarities and differences is needed.

In summary whilst an ecosystem is built around a value proposition it remains a complex network. The two are not mutually exclusive for researchers to investigate. An ecosystem as a complex network can resemble a nested hierarchy with core business (model) as a fully connected internal ecosystem with connections to hybrid or mesh external ecosystem/s. As an extension of Moore's (1996) I have illustrated how a network could look for a typical business ecosystem, with a variety of different network topologies for different players in different layers within the nested ecosystem in Figure

3.10. There are both direct and indirect links between the nested ecosystem layers to represent the different levels of strength of network connection. I have explored the type of ecosystem observed whilst observing the BIM and 3DCP companies as part of this research.



Adapted from 'The Death of Competition' (Moore 1996)

Figure 3.10 Ecosystem as a Complex Network

3.8.4 Stages of Ecosystem Development

Each business ecosystem develops in four distinct stages: *birth, expansion, leadership and self-renewal* (Moore, 1993:76). In the first stage, it requires an innovative firm to collaborate with suppliers and customers to present a viable product in which all the ecosystem partners can create and capture value. This is the entrepreneurial visionary process (Mintzberg *et al.*, 2009). Entrepreneurs and innovators focus on defining a value proposition for end customers and the best method for delivering it. At this stage, the initial winners to advance an innovation are those who best identify and implement this customer value proposition. During this birth stage of a business ecosystem typically finds companies the most open and cooperative. Ecosystem keystone players or pioneers collaborate with business partners to articulate the maximum value for customers whilst attracting a loyal band of follower companies who may otherwise join rival ecosystems (Moore, 1993).

For the second stage, business expansion, the innovation must give value to a large number of customers whilst also be scalable for the ecosystem players. This is where joining forces with more established companies with powerful marketing, distribution and sales helps the ecosystem outcompete other competing ecosystems (Moore, 1993).

After the expansion stage, if the ecosystem has now proved valuable and is exhibiting strong growth, is when leaders emerge as the industry matures. At this third stage, the power dynamics and negotiation process unfolds as bottlenecks or chokeholds occur once players in the ecosystem understand their importance to the value chain (Mintzberg *et al.*, 2009). Negotiation power and bargaining come to the fore and leaders emerge who followers trust and gravitate towards through alignment. Leaders may have control of the bottlenecks that limits other challengers from taking a keystone position (Moore, 1993).

As the industry matures, intense competition for market share amongst rival ecosystems or from the threat of a new innovation, means the players in the ecosystem must allow new innovations to flourish to allow a renewal rather than a value death spiral. In this final stage, incumbent communities are threatened and displaced by disruptors or external conditions alter the business environment through new government regulations, changing customer habits, or macroeconomic factors (Moore, 1993). An ecosystem's long-term success and ability to renew itself may depend on continuous innovation. Incumbent companies in an existing ecosystem have three choices. They may try to slow the growth of a new ecosystem, they may buy or adopt the emerging innovations into their own ecosystems or they can restructure themselves to face the new environment (Moore, 1993).

This research has observed both the early stages of ecosystem development for 3DCP sector as well as observed the wider more established actors in the BIM and general construction industry, to investigate what stage of development is currently exhibited.

3.8.5 Types of Business Ecosystem

Since the first definition by Moore (1993) the research field on business ecosystems has broadened into different aspects that address particular sectors or requirements of the players. Whilst all are considered under the business ecosystem umbrella, there are now several branches under the umbrella of business ecosystems : *Knowledge Ecosystems, Frugal Ecosystems, Innovation Ecosystems, Entrepreneurial Ecosystems*, *National Innovation Systems* and *Platform Ecosystems.*

Unfortunately, researchers use various ecosystem names due to the lack of consensus on the different types of ecosystems and their definitions. So, a business ecosystem consisting of firms focusing on new product development could be described as an innovation ecosystem or as a business ecosystem. For example Scaringella and Radziwon (2018) describes how Overholm (2015) considers a business ecosystem as equivalent to an innovation ecosystem, whilst Gomes *et al.* (2018) argue they are distinct. For the following analysis recall that the concept of a business ecosystem focuses on inter-organisational networks focused on a value proposition, sometimes with a large keystone player acting as the orchestrator. This type of ecosystem emphasises the value-creation process due to close collaboration between various ecosystem firms (Iansiti & Levien, 2004a; Scaringella & Radziwon, 2018).

3.8.5.1 Knowledge Ecosystems

Knowledge Ecosystems primary objective is the generation of new knowledge where the players are clustered in a geographically tight area and are usually centred around a university or research organisation. This differs to the primary activity in business ecosystems for value for customers with networks that can be spread across the globe with ecosystem leaders usually a large company, as the central or keystone player, providing resources to the network (Clarysse *et al.*, 2014). However a recent study on 3D printing firms in China has investigated the links between business and knowledge ecosystems and finds there may be value capture as research output transfers from a research organisation to a commercial enterprise (Xu *et al.*, 2018). The knowledge ecosystem acts a connective concept between business ecosystem and the cluster geographical approach. It still contains elements of collaboration and knowledge exchange whilst acknowledging the value-creation at the intersection of the business and academic worlds. The role that policymakers play in both knowledge and entrepreneurial ecosystems makes the knowledge ecosystem closer conceptually to the geographical approach (Scaringella & Radziwon, 2018). Clusters emerge when companies co-locate to increase their productivity by focusing on innovation to stimulate the formation of new businesses which raises regional competitiveness and economic performance. It is distinct from an innovation ecosystem due to the regional geographical boundary of the cluster compared to an innovation ecosystem where the boundary is not defined by any specific geographical location but through a collective functionality or value proposition (Dedehayir et al., 2018)

3.8.5.2 Frugal Ecosystems

Frugal Ecosystems (also referred to as Low-End, Resource-Constrained Ecosystems) reflect on Prahalad's work on the Base of the Pyramid (Prahalad & Hart, 2002; Prahalad & Mashelkar, 2010) observing how innovators can still make positive impact, even with resource constraints, to provide high value at low cost for the lower income communities. Recent articles have focused on how Western companies can use frugal innovation to build better business models incorporating local ecosystems to be successful (Winterhalter *et al.*, 2017) and how emerging economies are now exploring innovation (Pandit *et al.*, 2018) which again ties back the two research themes explored here for ecosystems and disruptive innovation.

3.8.5.3 Innovation Ecosystems

Innovation Ecosystems describe the collaborative effort of a diverse set of actors which focus on innovation and technological development (Iansiti & Levien, 2004a) with suppliers delivering key components and/or technologies, customers who steer the capabilities and focus of the products, and various other actors who add complementary products and services (Dedehayir *et al.*, 2018; Moore, 1996). An innovation ecosystem can be developed by companies from different industries that are located in close proximity to one another with a virtual presence a distinguishing factor between local (regional) and national innovation systems (Scaringella & Radziwon, 2018). Innovation ecosystem actors include producers, suppliers, distributors, financiers, universities and research institutions, complementary technologies manufacturers, policymakers and regulatory bodies (Dedehayir *et al.*, 2018; Moore, 1996). There is a move towards *innovation ecosystems*, modelled on Schumpeter's ideas of entrepreneurship and creative destruction, for entrepreneurial ventures aimed at the non-consumer market (Cañeque & Hart, 2017; Christensen *et al.*, 2019; Schumpeter, 1942). A pioneer venture firm builds an ecosystem for value creation. Other parties can join to co-innovate and then all parties can benefit from the value created. Each specific ecosystem sees roles for the actors and areas of complementary resources to create value. As the ecosystems evolve and new firms join, the emerging ecosystem creates opportunities in two ways (1) it helps new entrepreneurs to cognitively view their own ecosystem needs for value creation and (2) it represents a practical opportunity for market entry in a similar fashion to the pioneer firm. This concept has a dynamic approach compared to existing research which appear to see ecosystems as static (Overholm, 2015).

3.8.5.4 Entrepreneurial Ecosystems

Entrepreneurial Ecosystems which share similarities with innovation ecosystems have also started to appear but their focus is on the *"cultures, institutions, and networks that build up within a region over time*" (O'Connor *et al.*, 2018:5) rather than a specific new innovation or value chain. Entrepreneurial ecosystems still revolve around interactions between individuals and organisations, including financial intermediaries, universities and research institutions, suppliers and customers, companies and policymakers (Colombo *et al.*, 2019). However, an entrepreneurial ecosystem tends to emerge in a specific geographical region or a country, including both governmental level policymakers and entrepreneurs. This acknowledges the contribution of the actors on the individual and team level but to make a lasting contribution to the economy the support of the policymakers is necessary (Scaringella & Radziwon, 2018). The difference to knowledge ecosystems is that the value proposition is not focused around a specific innovation as the policymaker, which typically funds the research institute or university as a keystone, is interested in innovation in all sectors. This implies that an entrepreneurial ecosystem may contain numerous nested knowledge ecosystems at a regional level.

3.8.5.5 National Innovation System

The National Innovation System (NIS) concept is a special form of innovation ecosystem which revolves around systems based at the national or country level. The system actors share the aims of the NIS: (a) to be more innovative, (b) target economic growth and (c) strengthen their industrial competitiveness. This differs from the business ecosystem concept where the boundary is set around a value proposition on a particular product or service where the goals of each of the ecosystem players may not be the same (Tsujimoto *et al.*, 2018).

3.8.5.6 Platform Ecosystems

Platform Ecosystems link a platform sponsor to affiliated firms in a "hub and spoke" form, where end users log onto a central platform usually via shared technologies and/or technical standards (Jacobides et al., 2018). *"A platform is a set of solutions to problems that is made available to the members of the ecosystem through a set of access points or interfaces*" (Iansiti & Levien, 2004a:1600). Platforms are associated with network effects with the platform becoming more valuable as more users adopt it.

This increases the value of the platform to both the platform sponsor and the users increasing the incentives for other companies and users to adopt the platform and join the ecosystem (Gawer & Cusumano, 2014).

Platforms are distinct with a 'network effect' with additional users adopting the platform, raising the value to the platform owner and to the users. The access to an expanding network of users often leading to a new set of complementary innovations. This increases the incentives for more firms and users to join the platform ecosystem (Gawer & Cusumano, 2014).

Platforms can be internal through which a company can efficiently develop and produce a stream of products or external industry platforms where products, services, or technologies organised as a business ecosystem allows firms to develop their own complementary products, technologies (Gawer & Cusumano, 2014).

In effect the platform mediates transactions between sets of actors, with digital platforms often multi-sided interfaces between two or more sets of economic actors on different 'sides' of the platform, including providers of complementary assets (Helfat & Raubitschek, 2018). A platform can therefore be any combination of hardware and software that provides standards and interfaces to enable providers of complements to add value and interact with each other and end users (Teece, 2018b).

Large business networks can be considered as platforms where keystone companies such as Wal-Mart and Microsoft intentionally shape the collective performance of the networks of firms that depend on them by offering platforms on which others could build (Iansiti & Levien, 2004a). But these keystone companies are only strong if their platform business community is large, healthy, and growing as their fate is shared with that of the other members of their business network. Like organic ecosystem they focus on the collective well-being of the network rather than their internal capabilities by playing a keystone role.(Iansiti & Levien, 2004a).

In summary, the various ecosystems described all contain the basic components of an ecosystem but there seems to be a gap in the research on how to classify the type of ecosystem a company finds itself in. An acknowledgement of the differences between the types may help a new venture or incumbent formulate its ecosystem strategy to gain maximum value creation for itself and the other actors surrounding its new innovation. This research attempts to observe the types of ecosystem seen in innovative companies in the construction sector.

3.8.6 Ecosystem Strategy

According to Adner (2017:47) ecosystem strategy can be defined "*by the way in which a focal firm approaches the alignment of partners and secures its role in a competitive ecosystem.*"

Ecosystem strategy is not confined to traditional industry boundaries as it is defined by the strength and type of organisational interactions that occur in the ecosystem (Iansiti & Levien, 2004a). Ecosystem strategy is an iterative process depending on the players and complementarities so companies must match their strategy to their ecosystem. They must track partners and competitors development, as well as their own, whilst monitoring interdependence and initiative risks (Adner, 2006). All the actors in an ecosystem, either well established companies or new ventures have inter-organisational dependences (Zahra & Nambisan, 2012) so they must work in collaboration to develop complementary capabilities (Moore, 2006). The strategy needs to identify if the ecosystem will evolve through a central focus firm with relevant stakeholders (Freeman, 1984) or through a decentred network (Calton *et al.*, 2013).

For nascent technology organisations a grassroots approach usually exists where *"strategies grow initially like weeds in a garden, they are not cultivated like tomatoes in a hothouse"* (Mintzberg *et al.*, 2009:205). For companies looking to develop a market creating innovation, these new ventures must be willing to learn and adapt their strategy (Christensen *et al.*, 2019). To be successful these firms need to develop an ecosystem strategy and map out a value blueprint that makes its ecosystem and any dependencies explicit. Characterise your end customer, suppliers, intermediaries and complementors and consider the level of co-innovation and adoption risk in this ecosystem (Adner, 2012). This builds on three basic foundations for ecosystem strategy: (1) how companies decide boundaries between technologies, products, and organisations; (2) how the ecosystem players collaborate; (3) how do players operate and govern the business network (Iansiti & Levien, 2004a).

3.8.6.1 Ecosystem Boundary and Complementarities

The ecosystem strategy must understand the boundaries of technologies and organisations in the ecosystem. Traditional business strategies such as Michael Porter's (1980; 1985) five forces framework is of limited value in a fast, technologically changing environment, especially in an underdeveloped market, as it underplays network effects and externalities, innovation and evolution of technologies, evolution of institutions and the role of the focus firm to shape the ecosystem itself (Teece, 2007).

Seniors executives need to understand how their company's skillset can effect change in a sector. Teece (2007) states that a company's strong dynamic capabilities can not only adapt to business ecosystems, but also shape them through innovation and collaboration with other ecosystem players. When looked at through the disruptive innovation and ecosystem lenses a strategy can help the search for both value creation and value capture.

A firm with a more entrepreneurial management team can adopt Schumpeterian methods to manage the *"co-evolution and complex interaction…between the (business) ecosystem participants"* (Teece, 2007:1323). Externalities play a far more important role in an emerging industry, with each firm balancing self-interest against industry development for a successful marketplace adoption. Therefore, the actors in the emergent technology ecosystem need to take a dynamic approach to the environment through three clusters: "*sensing, seizing and transforming"* (Teece, 2011:31). Sensing is the entrepreneurial process that sees new opportunities and liaise with other parts of the ecosystem. Seizing is designing an appropriate business model that can create and capture value. Transforming refers to the creative destruction of the existing to make way for the new.

Complementary markets are a key component for an ecosystem strategy. Early-mover advantage can seem attractive to a new venture but if the ecosystem boundary does not contain the complementary markets necessary for a successful launch then it may fail. Adner (2012) cites the launch of the iPod three years later than the MPMan MP3 player to showcase how it can pay to wait until all elements of the ecosystem are in place, with unobstructed access to the market, the chance to establish industry standards and lasting brand recognition that is instilled into end customers. Apple may not have been first to invent the MP3 player, but they understood the need for discipline and perspective. Firms must view the ecosystem as a puzzle where nothing is seen until it is complete. In this scenario the first player to put down the first piece doesn't win, it is those who see the end piece positioned that are successful (Adner, 2012). Smart timing for a new technology requires a wide lens approach to the ecosystem dynamics and value proposition and firms must decide their role, positioning and timing in the ecosystem.

3.8.6.2 Ecosystem Collaboration or Competition

Whilst one of Porter's (1980; 1985) five forces business strategy is rivalry among competitors, ecosystem studies have explored coopetition and collaboration (Adner *et al.*, 2013; Ansari *et al.*, 2016; Moore, 1993; Overholm, 2015). Coopetition or

cooperative competition, refers to the interplay between competitors who need to work together rather than compete to reach a common goal (Brandenburger & Nalebuff, 1996). Collaboration can be defined as a set of networked players with shared objectives, synchronising mutual interests and coordination of mutual activities through continuous negotiations. It can be viewed as the most developed form of interactive communication. Higher levels of integration differentiates collaboration from other types of relationships, such as networking and cooperation, as co-creation of new values requires the participants to adopt actors to have a common strategy, joint identity, joint goals and joint responsibilities (Russell & Smorodinskaya, 2018).

A summary of the stages of an ecosystem along the lines of collaboration and competition was first given by Moore (1993:77). He viewed the levels of competition and collaboration to be dynamic and modified during the various stages of ecosystem development. In the earliest birth stage, innovators see the highest levels of collaboration as all ecosystem players have an interest in launching a new product. During the expansion stage new actors are brought into the ecosystem to scale up supply and a wider target market, but levels of cooperation are still high. It is at the third or leadership stage that key players begin to use power and negotiation tactics to compete, rather than collaborate, to win market share. Competition centres around control of bottlenecks and chokepoints on key components within the ecosystem. Once leaders have been established, they try to create high barriers to entry for new entrants or buy them out before they become a threat.

Ecosystem strategy research has studied the effects of both competition and cooperation (Adner, 2006; Adner & Kapoor, 2010) but to date most research has mainly concentrated on firms in developed countries, mainly in technology firms. Little research has been done in the construction sector. And at present little research has been done on collaboration in ecosystems for new ventures, with a few exceptions on solar service ventures (Hannah & Eisenhardt, 2017; Overholm, 2015). Most of the research is Western economy based, not generalisable for construction in developing countries.

3.8.6.3 Ecosystem Governance

A key management function is to identify and organise value-creating combinations within divisions of the firm, amongst the ecosystem players and with any other supporting institutions (Teece, 2007). Whilst business ecosystems develop through either co-operation or competition (Khanna *et al.*, 1998), innovative or nascent technology requires firms to navigate cooperation and competition dynamically over

time (Hannah & Eisenhardt, 2017:01). Researching residential solar firms in the US, they looked at the bottlenecks that emerge in new sectors and how they can be used as strategies for growth. They find that a bottleneck ecosystem strategy is the most value creating compared to a component or system strategy. Strategies to identify and control bottlenecks are useful for nascent ecosystems which are dynamic with undefined industry structures, with unclear product or component definitions, rapidly changing innovation in components, and uncertainty about potential rivals. As the ecosystem develops, so the strategy changes between collaboration and competition. To capture a large part of the value from a new innovation, the firm or enterprise must have the ability to identify and control the '*bottleneck assets'* or *'choke points'* in the value chain from invention through to market (Teece, 1986; Teece, 2007).

Adner (2012) considers the case of electric vehicles (EV). For EV cars the technology has been around for 100 years, but cheap oil and Ford's mass manufacturing process won the race to mainstream adoption. It has only been the emergence of environmentally conscious consumers and aggressive government policy makers that has brought about a change in perception on combustion engines. But the case for electric vehicle has been perceived as an ecosystem problem, in which multiple elements need to come together to enable the value proposition with three bottlenecks to mass adoption: (1) EV's are currently more expensive (2) range on one battery charge is too low (3) insufficient charging infrastructure. Similar to BIM with policymakers focus on innovation to lift productivity, a broad array of private and public actors is required through an ecosystem approach to overcome these bottlenecks. Since Adner's research was published in (2012), the past eight years have certainly seen a massive in improvement to the first two bottlenecks, but more action is needed for the last one before mainstream adoption can begin. Constructing an ecosystem takes both time and focus but just as the automotive ecosystem has evolved so the construction industry can evolve. Determining value creation needs to involve the external environment as internal innovations in the focus firm will not be enough to solve industry level challenges. Competitors and suppliers in the ecosystem will create bottlenecks and depending where in the value chain these are will affect the likelihood of success of the focus firm unless it has a clear ecosystem strategy (Adner & Kapoor, 2010).

The governance within the ecosystem will also be determined by the roles that firms wish to play within it. Dedehayir *et al.* (2018) studied how innovation ecosystems are created and the different types of roles (behaviours or activities) undertaken by the ecosystem actors during its formation. Others have studied the roles of *platform leaders*, typically large companies driving industrywide innovation through a complex

system of separately developed components of a technology and *complementors*, typically companies making the ancillary products to expand the platform's marketplace (Brandenburger & Nalebuff, 1996; Cusumano & Gawer, 2002).

Ecosystem players must decide if they want to be a leader/pioneer or a follower in their ecosystem (Adner, 2012; Iansiti & Levien, 2004a). A keystone strategy enables value creation in a large network through interconnected assets that can be easily scaled and shared by an extensive network of partners (Iansiti & Levien, 2004a). But the ecosystem health will fail if a network keystone player does not share some of the value it creates.

If a company is already a large well-established, it may want to be a keystone player or leader, but smaller new ventures will need to decide if any others will follow them or whether initially should be a follower. In most cases, being the ecosystem leader or pioneer entails up-front investments and their core challenge is creating value for the end user whilst ensuring that all essential partners also obtain value from their participation. At the birth stage a leader or keystone must be brave enough to sacrifice some returns whilst heavily investing in the hope of outsized returns in the end when the ecosystem is established. (Adner, 2012; Adner & Kapoor, 2010).

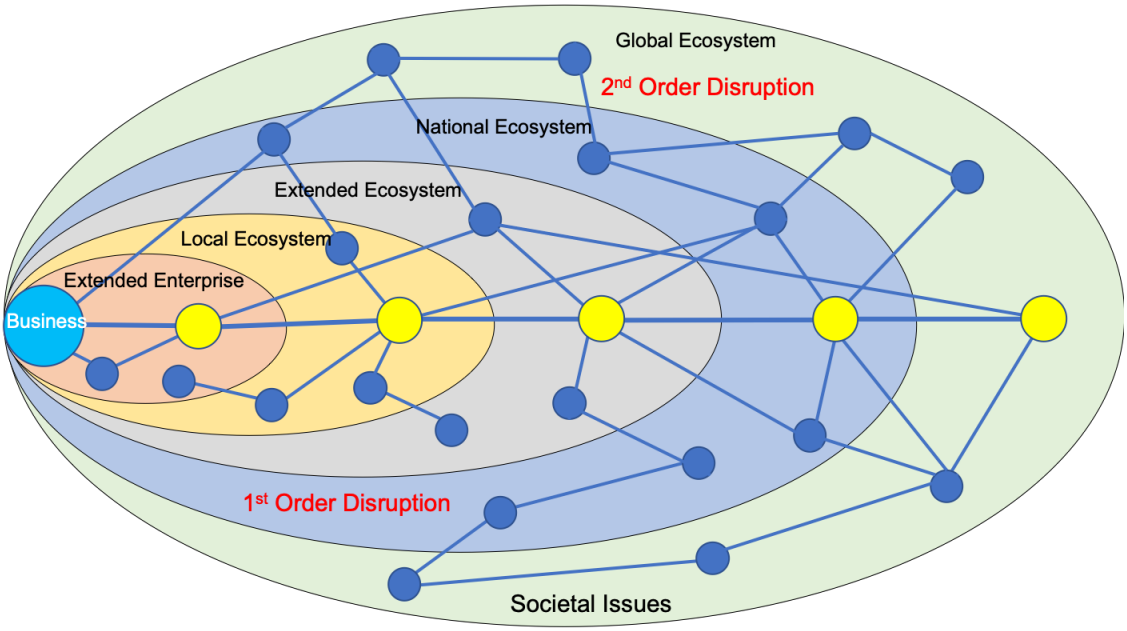
For ecosystem followers, smaller initial commitments imply smaller downside risk. As opposed to a leader, a follower's investment is lower and more quickly recovered and unlike the leader who is managing many relationships, a follower can concentrate on his own. Whilst they receive a smaller return for their smaller investment, followers need to capture value as well as the leader for the ecosystem to thrive (Adner, 2012).

3.9 Extending Existing Knowledge

Whilst a DBA represents a practical application of existing theories, it is also an opportunity to discuss how this research and literature review can add to existing knowledge in these fields.

As I am focused on the ecosystems that the 3DCP and BIM participants are in the process of constructing, I started from the preconceived idea of Moore (1996) with an interconnected network between the core business, extended enterprise and business ecosystem (See Figure 3.8 and Figure 3.10 above). However I still referred back to the Tansley (1935) definition of an ecosystem as a complex network, so I considered how graph and network theory describes the linkages between all of these actors (Barabasi, 2014) in an ecosystem as well as considering the magnitude of disruption that occurs due to different types of technological innovation (Schuelke-Leech, 2018). To my mind there is a refinement that can be made to Moore's original work as the business

ecosystem can be divided into multiple levels, just as in nature the path from tadpole to frog relies on multiple sub ecosystems as well as the larger environmental factors present. The growth path can be affected by local disruptions (tadpole eaten by a fish) to larger disruptions (a hurricane wipes away the whole pond). I also played with the idea of six degrees of separation, sometimes described as social network or complexity theory (Barabasi, 2014; Russell & Smorodinskaya, 2018) to consider how a platform ecosystem could develop (Gawer & Cusumano, 2014) and who is the platform or ecosystem leader. To visualise this concept, I extended the three levels of Moore into six levels and incorporated the two orders of disruption, as illustrated in Figure 3.11 below.



Adapted from Moore (1996), Russell & Smorodinskaya (*2018), Schuelke-Leech (2018)*

Figure 3.11 Six Degrees of Nested Ecosystems

I also considered the strength of connection within the 6 layers along the degrees of separation for different types of ecosystem with reference to both the top down government view and a bottom up end user or company view. This is to further define the boundary condition applied by Adner (2017) on the extent of the web of interdependencies, such as should a complementor's supplier's supplier be part of the ecosystem plan. This also incorporates the emergent research by Shipilov and Gawer (2020) to reconnect the fields of networks and ecosystem research through the strength of connections. See Figure 3.12 & Figure 3.13 for two illustrations of how the strength of the connection shifts as the players become only an affiliate rather than a structured player with a specific role in a tighter ecosystem layer to the core business as an extension to the recent work by Adner (2017). This also acknowledges the definition on ecosystem theory by Jacobides *et al.* (2018) that considers the idea of

technological modularity, when components within the ecosystem can be produced by various players with limited co-ordination necessary. They view non-generic complementarities as key to the ecosystem structure rather than an aggregate of buyer-supplier arrangements in hierarchy based systems. However, I think there needs to be a method to distinguish the generic from the non-generic components along an axis and measure the strength of the ties. Whilst they surmise that when making a cup of tea, the source of the water is generic and can therefore be excluded from the boundary of the ecosystem, I believe that all component parts of an ecosystem should be considered and acknowledged, but can then be defined by the strength of the connection to the final product. In Figure 3.13, the raw material supplier may be considered generic, it is still included in the ecosystem but recognised as being a distant affiliate with a weak connection.

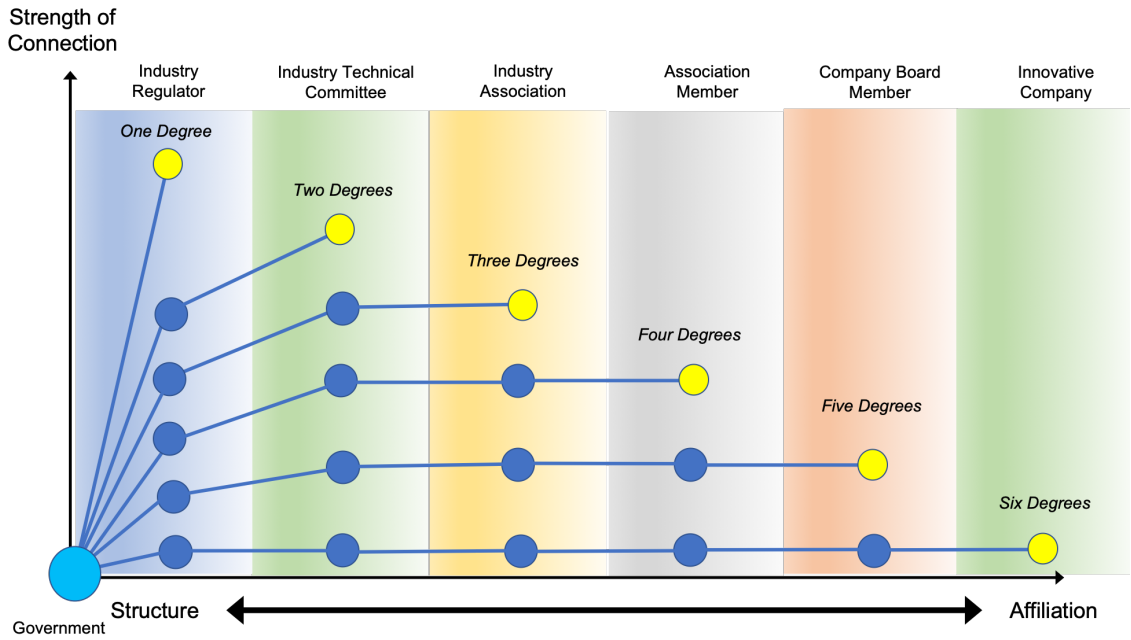


Figure 3.12 Ecosystem Boundary: Government

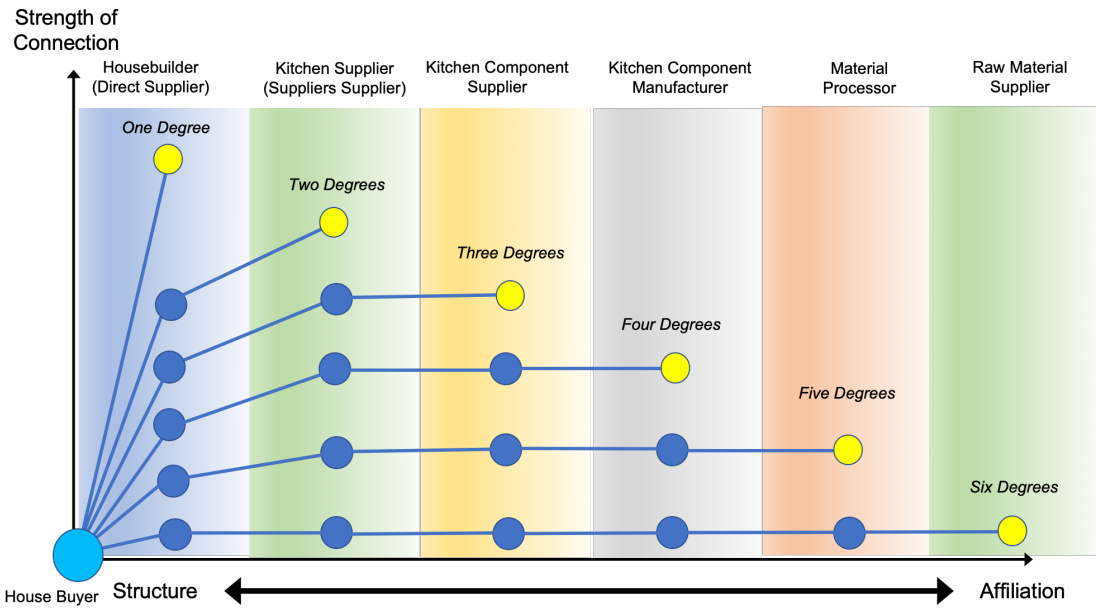


Figure 3.13 Ecosystem Boundary: House Buyer

Specifically, for the construction industry, I considered what six ecosystem layers are nested together and how I would categorise their ecosystem in reference to the existing research. Using the definitions of the types of ecosystem described in 3.8.5 above, I then referenced the layers along both a magnitude and growth phase to describe the current situation of the participants in this study (whether a sixth level of ecosystem definition is required to neatly correlate to the six degrees of separation, I leave to others. As this is a DBA, I am not trying to present new theory, just an extension and combination of existing theories, but perhaps the circular economy and societal issues raises the possibility of a *Global* layer to represent the last and largest of the nested ecosystems).

For 3DCP new ventures, their early ecosystem most resembles that of a knowledge ecosystem at outset. They are deeply connected with a small community of like-minded companies and research facilities and can be geographically clustered with a stronger structure surrounding them. For their next step, the leaders in this technology are now expanding into a wider innovation ecosystem which includes a much more widely dispersed community but still with a strong value proposition focused on the development and marketing of their innovation. As they move from initial proof of concept to engage in more pilot projects with the beginnings of commercial applications, starting this year 2020, these will soon further develop into an emergent business ecosystem, but it is not clear whether there will be any keystone player at this stage. With consideration to Adner (2017), I describe the initial knowledge ecosystem as more of a structure than an affiliation, with a focused value proposition requiring all

ecosystem players to be specifically chosen for their ability to move the technology forward. I have called this a 'bottom up' ecosystem strategy as I expect the stages of growth to be organic.

However, for the BIM participants and incumbent construction industry firms, they are already well established firms, already operating in a business ecosystem. They no longer have as many tight interconnections to research or innovation bodies and do not therefore resemble a knowledge or innovation ecosystem. With consideration that it was government mandates and initiatives that led to the creation of the BIM levels acknowledges the government and industry leaders acting as the keystone player (Iansiti & Levien, 2004a). Noting the enormous size of the industry, I describe this as a 'top down' ecosystem strategy as it will impact all players in the wider national (or global) industry ecosystem. As the level of connectedness between an individual firm and the government passes through the multiple layers of the nested ecosystems, the degree of association is more an affiliation than a structure (Adner, 2017) as the value proposition is more varied for the individual firms although all are still affected by the directives (using the previous analogy of a hurricane, all get wet but some more than others).

Also, of note is how the different types of business ecosystems interact with each other and how they relate to companies at different stages of their development. As described above from the literature, the different ecosystems have overlaps but also distinct characteristics. Small start-ups are more likely to use a knowledge ecosystem clustered around a research body before branching into a wider innovation or business ecosystem. Incumbent firms once they have developed a working business ecosystem, whether quickly such as Airbnb or Uber, or over a longer period such as Apple, Microsoft, Samsung, have the opportunity to pivot into a platform ecosystem leader and reach a wider level of potential suppliers and end users. Again, this is by incorporating the new innovation, be it a technology or process, into their business model. Incumbent firms need to decide whether to remain in their current business ecosystem or utilise an ecosystem strategy to move into a platform. Autodesk is trying to do this in CAD and BIM software, Microsoft is already a cloud platform provider for many firms but is now targeting the construction sector with this technology. Other companies may lose out in this competitive race and will remain part of the smaller business ecosystem layer perhaps as a leader in their sub sector but as a follower in the larger platform ecosystem. At the far end of the scale, National Innovation Systems encompass a country-wide ecosystem that is government lead and includes multiple industrial sectors and sub ecosystems. Incorporating the ecosystem as structure or affiliation also suggests that a tighter knit group of companies with high strength of

connections are more likely to emerge in knowledge ecosystems, whereas at the other extreme a National Innovation System can be viewed as a looser affiliation for most companies. Using the six degrees of separation and the nested ecosystem layers visually illustrates this. See Figure 3.14 below.

I have also incorporated elements of disruptive innovation as it is more typical from my research that the 3DCP new ventures are focused on what they believe is a market creating innovation, with large value to be created and captured if successful, versus BIM, which I consider a sustaining and efficiency innovation for the incumbent firms (Christensen *et al.*, 2018; Christensen *et al.*, 2019). I am cognisant of the fact that BIM is a key component of the 3DCP firms' strategy, but it is not the whole innovation, which I still see as the overall business model innovation rather than a specific technology or process.

With reference to the magnitude of disruption, as 3DCP is still a sector in its infancy, the disruption is so far small and localised, so represents a 1st order disruption (Schuelke-Leech, 2018). For BIM, as an industry wide innovation, this represents a 2nd order disruption.

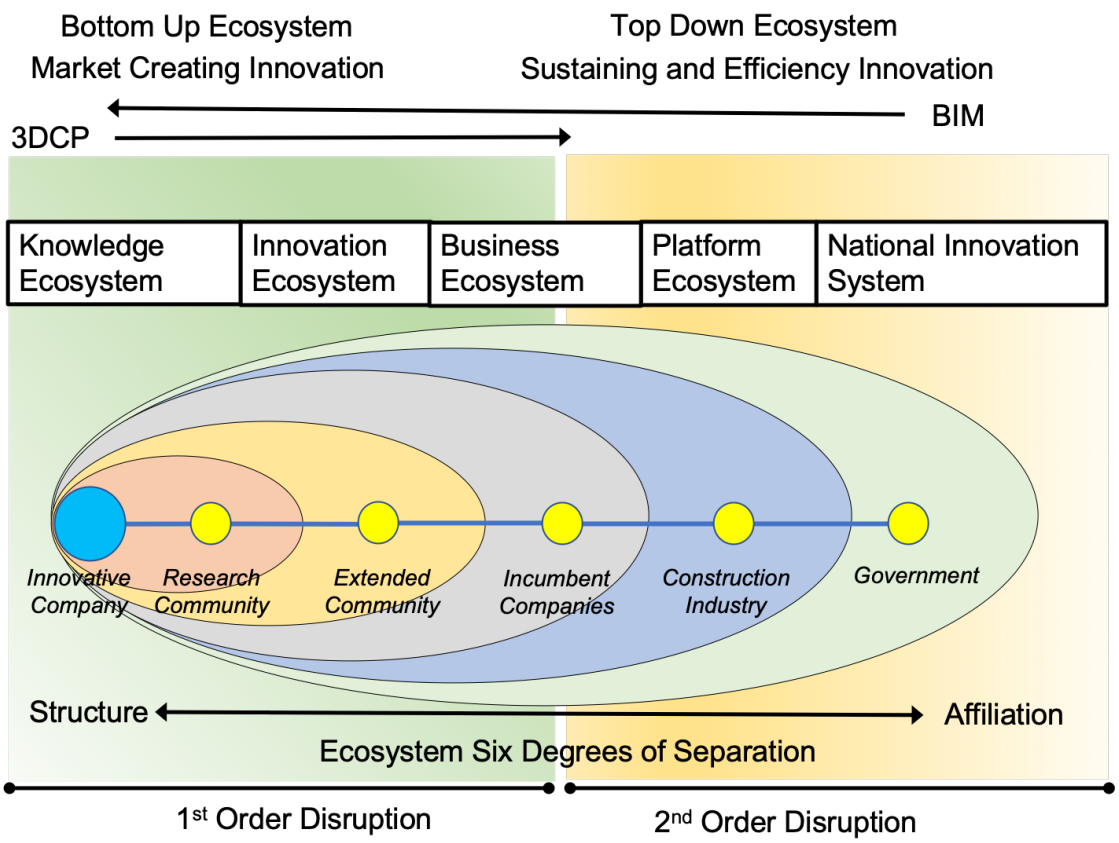


Figure 3.14 Connecting Ecosystems and Disruption levels

To consider how this extends Christensen's original definition of disruptive innovation (Christensen, 1997), I have incorporated the nested ecosystem viewpoint into his original graph by adding the stages of ecosystem into the areas populated by the different customer types. I have also incorporated D'Aveni (2018) four stages of adoption, *Concept, Early, Mainstream and Ubiquitous Adoption*, which I find analogous to the four stages of ecosystem *Birth, Expansion, Mainstream, Renewal,* described by Moore (1993). By doing so I can now have a placeholder for each of the firms interviewed in this research and a guide for future ventures. See Figure 3.15 below for an illustration of this extension to both ecosystem and disruptive innovation literature.

For example, a new venture launching a new innovation will start at the birth stage within a knowledge ecosystem, at the bottom left quadrant on this graph, targeting non-consumers with a (hopefully) market-creating innovation. As they grow and commercialise their product, their ecosystem expands and morphs into a business or platform ecosystem and they appeal to the mainstream customers with eventual mainstream adoption.

Another example could be an incumbent construction company considering their BIM strategy. They are already within a business ecosystem, covering a certain proportion of the existing customer base therefore they sit in the middle of this graph. They must now consider their business model innovation strategy. They have the choice to switch to a platform strategy to become a manufacturing titan and a platform leader (Cusumano & Gawer, 2002; D'Aveni, 2018) and so reach a wider base of customers and suppliers, or to continue as an ecosystem follower. They have the choice of remaining an incumbent or becoming a disruptor depending on their choice of innovation (sustaining, efficiency or market creating).

For a government, they already touch the whole customer base and sit in the largest ecosystem layer, so top right quadrant on the graph. For BIM initiatives, I see this as a renewal stage but still only a sustaining & efficiency innovation. If governments decide to push 3DCP and a wholesale change to construction using modern methods of manufacturing, then they may become a market creating disruptor as well.

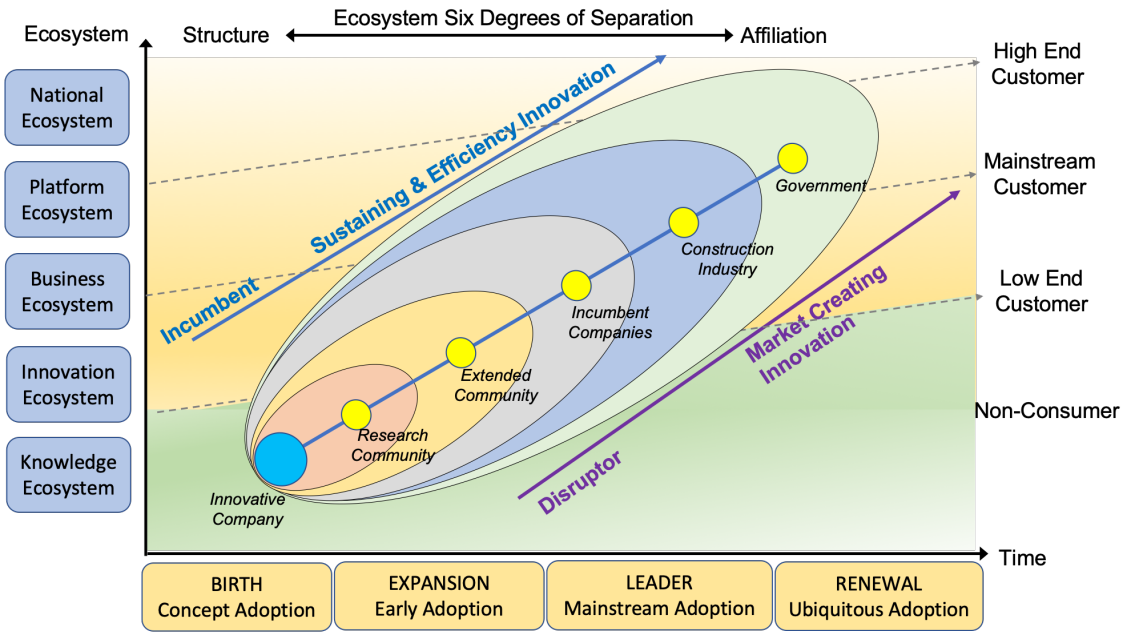


Figure 3.15 Amalgamation of Disruptive Innovation and Ecosystem research

Once the typology and positioning of a company's place in the various descriptions of ecosystems and innovation type has been established, consideration of an ecosystem strategy must be made. As previously discussed in 3.5.2 above consider the many similarities between ecosystem and stakeholder theory (Freeman, 1984) especially in connection with ecosystem strategy. An adaption of Freeman's enterprise strategy as illustrated in Figure 3.4 represents my interpretation of how ventures should consider their ecosystem strategy and links the current ecosystem research (Adner, 2006; Ansari *et al.*, 2016) back to pre-existing strategic management theory. This gives a stronger shoulder to stand on, especially as it also links back to the societal impact that ecosystems both natural and business make through their value proposition.

3.10 Summary

From the review of the existing literature, it is clear that successfully building an ecosystem to create value from an innovation requires further research. It is more about the vision for an entire business model to introduce potentially market-creating innovations and less about the actual product being sold. However little research has been done on ecosystems for new ventures or how they are formed, with a few exceptions such as analysis on solar service ventures (Overholm, 2015) and TiVo (Ansari *et al.*, 2016). Missing in the academic literature is social science research for bringing innovation into construction through a new technology (3DCP) or process (BIM or digital twin).

Recent research by Christensen *et al.* (2019:29) list five attributes that innovators and new ventures should consider when creating a new market with their innovation: (1) A business model that targets the non-consumers (2) an enabling technology (3) a new value network (4) an emergent strategy (5) executive support.

These five areas are consistent with my literature review and research study. They fall under the ecosystem strategy adapted from Freeman, for the three main analytical areas: ecosystem actor, value proposition and societal issues described in Figure 3.4 above.

Using the review articles on disruptive innovation and ecosystems I have subsequently constructed a research question and interview protocol. Through purposive sampling of relevant construction ecosystem actors, I observed the business models that companies are employing whilst using the enabling technologies of 3DCP and BIM. Through interviews with the visionary leaders of their senior executives I could observe how they build their value network (ecosystem) and ecosystem strategy. Using my extension of Moore's and Christensen's theories to identify and classify the positioning and type of innovation and ecosystem a practical toolkit can then be constructed to assist other innovative companies in the construction industry.

4 Methods

4.1 Introduction

The Methods chapter is a report on the process and actions undertaken by me so that future researchers can replicated my approach. The chapter explains the methods employed, the reasons for choosing them, an outline of the research setting, the selection of cases, and the justifications and limitations of taking this approach. It explains the systematic approach employed for data collection and analysis and explains exactly how I obtained the findings (Gioia *et al.*, 2013). It explains the pros and cons of the qualitative method used and the reasoning why it was the appropriate one to use. It is detailed enough to allow replication, shows why these methods are appropriate for my study, highlights the boundaries of the study and it intended to be a clear and concise 'cooking recipe' to be followed.

4.2 Summary of Method Approach

My research study asks an epistemological question "*How do new ventures successfully create an ecosystem to capture value from a disruptive technology?"* to understand the phenomenon of interest through the interpretation of participant action and beliefs found in collected data.

However the lack of existing research on new ventures in the construction industry at the intersection of disruptive innovation and ecosystems theory led to pragmatic, inductive qualitative case study research (Eisenhardt, 1989; Yin, 1984).

The focus is on a selection of companies involved in bringing innovations to the construction industry as they represent an observable unit of analysis that can inform practice and thereby make a contribution to knowledge (Pratt, 2009). I was purposely selective when choosing companies to target and as I have no prior experience with the construction industry I could research from the stance of an external observer.

It is a pragmatic approach, as I believe that researchers should employ the most appropriate and practical method to answer the research question with the emphasis on understanding people and situations rather than just observable facts (Lee & Lings, 2008; Savin-Baden & Major, 2013). In my view pragmatism is a compromise between how we construct the world we live in vs what we can observe and explain about it (Guba & Lincoln, 1994).

I chose an inductive, qualitative research approach as I believed a series of interviews was the best way to gather information about new ventures using a new innovative technology in an emergent sector.

Due to the nascent early stage of many of the companies involved in construction innovation I choose case study research using a single case (embedded) design with the ecosystem surrounding innovation in construction as the case study, and companies innovating with technology as the multiple embedded units of analysis (Yin, 2018).

For the data analysis I used an adaptation of the Gioia methodology (Gioia *et al.*, 2013) which is similar to the approach of recent researchers studying ecosystems (Dattee *et al.*, 2018).

The overall process undertaken for this research is illustrated in Figure 4.1 below.

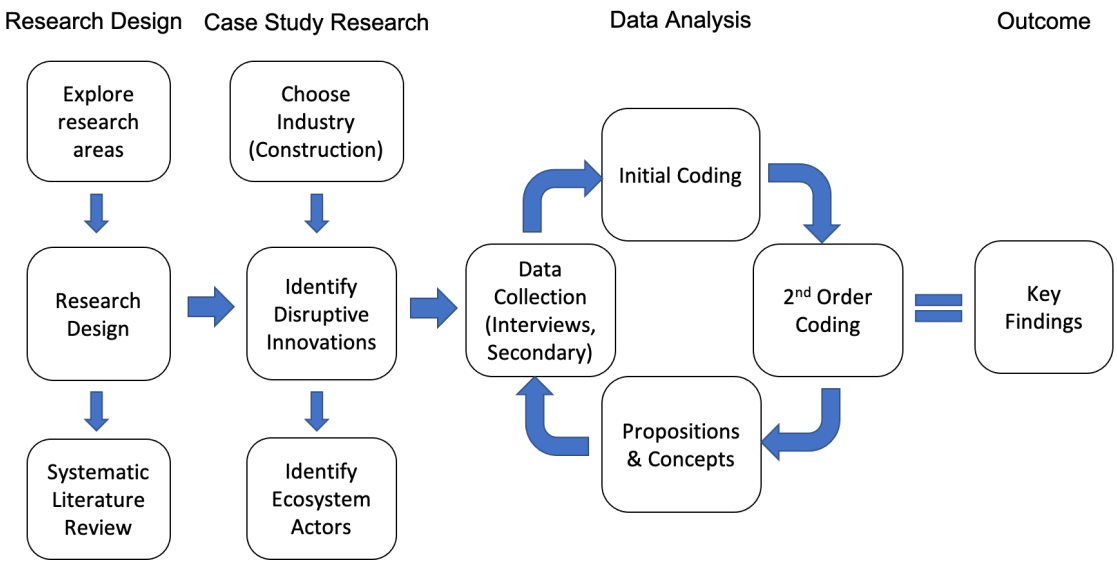


Figure 4.1 Summary of Method Approach

4.3 Research Design

A qualitative research design is the logic that *"links the data to be collected (and the conclusions to be drawn) to the initial questions of the study"* (Yin, 2018:24). In case study research, five components of a research design are important: *(1) The research question; (2) propositions; (3) cases and case boundaries; (4) The logic linking the data to the propositions; (5) The criteria for interpreting the findings* (Yin, 2018:27).

4.3.1 The Research Question

A DBA can be described as *theory informed practice,* contrasting to a PhD which aims to contribute to theory. DBA research explores the latest academic theories to try and apply them to the business world. Commercial research rarely employs theory whereas academic research should make a contribution to existing theoretical knowledge whilst being conducted in a rigorous way (Lee & Lings, 2008). This DBA was initially focused

on social entrepreneurship (SE) and I spent the first two years learning about SE, hybrid organisations, business models and ecosystems, as I am passionate about making this world a better place. After my first review in 2018, I reflected on the difference between commercial and academic research and decided that my research should look at a specific innovation to address a specific problem in a specific industry and thereby make a practical contribution to knowledge through the application of research. Therefore, this research aims to deliver a toolkit to help eliminate housing shortages across the world through better practices for construction companies to capture value from emerging technologies. The progression of my research question is shown below in Figure 4.2:

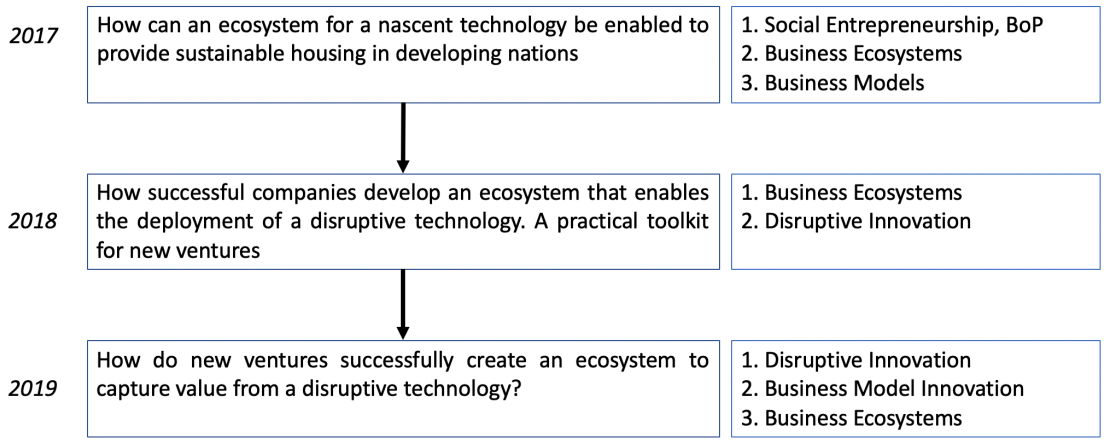


Figure 4.2 Evolution of Research Question

4.3.2 Propositions

I developed initial propositions to guide the anticipated case study and generalise its findings; Each proposition focuses on areas to be examined within the scope of this research study: '*How do new ventures successfully create an ecosystem to capture value from a disruptive technology?'* For example, how does a 3DCP print manufacturer collaborate with construction industry ecosystem players to provide a new innovative service to build houses?

I developed themes found in the existing research to form the basis for the interview protocol questions. Some of my initial questions included: Is there a rationale for forming a strategic alliance instead of joining the value proposition in an ecosystem? If so, do those companies with a strategic partner develop faster? How do research universities help new ventures develop an innovation? Using the analogy of the goldrush where the merchants grew richer than the miners, will it be the technology suppliers (3D printer manufacturers or BIM software providers) or the construction

companies that will capture the most value from the innovation? Is it a level playing field for the innovators or will bottlenecks described in previous research hinder their development? And finally do the participants see new technologies coming into construction as disruptive?

These propositions have some initial direction and rationale, as they are based on reflections after I conducted the literature review, even if these initial assumptions are later proved wrong (Yin, 2018). The goal for considering them is that if the propositions are consistent with most or all of the cases, through pattern matching the theory to the data can result in the practical toolkit (Eisenhardt & Graebner, 2007). These propositions and the thematic questions in the interview protocol were used in the semi structured interviews with participants which is detailed in 4.5.5.2 below.

4.3.3 Cases and Case Boundaries

Outlining case boundaries are the foundations for building the research question as *'the tentative definition of your case can derive from the way you define your initial research question'* (Yin, 2018:29).

I identified the case study design (single case embedded) as described below. This research is focused on a particular subset of the construction industry, concentrating on firms introducing new technologies for construction purposes. In this research I have taken the ecosystem surrounding innovation in the construction industry as my *single case* context and therefore its boundary. I have used the companies employing the latest innovations to be the *embedded* multiple units of analysis within that boundary. These companies represent a real-world phenomenon with observable characteristics (Yin, 2018).

Using a wide range of companies ensures that there is no common company mindset or culture to dismiss or filter out of the results. The use of multiple companies will allow a robustness and generalisability to the findings because the propositions are grounded from wider and more varied empirical evidence (Eisenhardt & Graebner, 2007).

4.3.4 The Logic Linking the Propositions to the Data

My main analytical approach to link the propositions to the collected data is through pattern matching and cross case synthesis as detailed in Data Analysis below. As the data collected was large the use of NVivo helped me to manipulate the large amount of data into smaller themes and codes which could then be visually analysed. As the findings are not derived from one unit of analysis, such as a single company, this case study presents an opportunity to shed empirical light on the existing literatures

theoretical concepts. The initial propositions helped articulate the design of this case study and the interview protocol, whilst my findings lead to generalisations, in the form of the practical toolkit that (a) corroborate, modify, reject, or advance those referenced concepts or (b) present new concepts that arose from this case study research (Yin, 2018). I used extant research literature as a guide for defining the case, whilst the case research methodology provides the specific steps to link the initial propositions to the data collected. In line with the inductive approach, the propositions altered as the collected data was analysed leading to different outcomes.

4.3.5 The Criteria for Interpretation of the Findings

I evaluated the design against the four main criteria for maintaining the quality of a case study: *construct validity* (correct measures used for the concepts), *internal validity* (for explanatory studies where conditions lead to other conditions), *external validity* (are the results generalisable) and *reliability* (is the research process repeatable with the same results) (Yin, 2018).

Construct validity was achieved through collecting multiple sources of data with key informants purposively selected. Internal validity has been achieved through pattern matching and addressing plausible rival explanations. External validity is more difficult considering this is such a nascent sub sector of the vast construction industry. Future research on companies after mainstream adoption may act as confirmation. Reliability has been achieved through using the case study protocol and database whilst maintaining a chain of evidence.

4.4 Case Study Research

4.4.1 An Inductive Qualitative Research Method

An inductive approach is appropriate to observe and conceptualise how phenomena develop with the emergence of theory from the data, especially for emerging industries (Eisenhardt *et al.*, 2016). Qualitative research methods, or *naturalistic inquiry*, refers to theories of interpretation and employ various strategies for the collection, organisation and analysis of material obtained through conversations with people (Malterud (2001:398) cited in (Savin-Baden & Major, 2013)). As I wanted to understand the issues and strategies employed in launching a new innovation, I considered the best approach was to interview senior business executives in the emerging field of 3DCP, BIM and associated sectors. As this area is so new, little data exists in the shape of company accounts, reports or industry trade bodies and standards, so a quantitative

study would not be appropriate. "*Qualitative researchers live messier lives"* as *"business reality is risky, ambiguous, fuzzy, chaotic and unpredictable"* (Professor Evert Gummesson cited in (Lee & Lings, 2008:205). Qualitative methods have a more flexible, less conformist nature than quantitative methods, so qualitative may be messy but with a rigorous approach to the systematic handling and organisation of the data, a richer and more nuanced set of results can emerge. Through interviews with people, I could understand if there were any commonalities in their approach to problems and propose solutions. Inductive methods are appropriate for building the practical toolkit from the data as these are useful in situations where there is limited theory or where problems have no clear answers (Eisenhardt *et al.*, 2016). They involve deep immersion in the data, involve case selection that illuminate relationships amongst constructs and mainly rely on a grounded theory methodological process (Eisenhardt *et al.*, 2016). Scholars have now sought a systematic approach to new concept development and grounded theory to bring qualitative rigor to inductive research (Gioia *et al.*, 2013). However, there are two major potential pitfalls when conducting an inductive qualitative study: (1) lack of balance between theory and data (2) making qualitative research appear quantitative, so I have been mindful of both whilst writing this thesis (Pratt, 2009).

4.4.2 A Pragmatic Approach to Case Study Research

As seen in health, education and business, I adopt a pragmatic approach: "*An approach that draws upon the most sensible and practical methods available in order to give an answer to a given research question*" (Savin-Baden & Major, 2013:171). A pragmatic approach does not mean that it is any less rigorous as it can lead to an *interpretive description* of a situation (Thorne et al,1997 cited in (Savin-Baden & Major, 2013). Pragmatism requires employing a sound methodological approach but one that is best suited to the research question and setting so I researched all the main qualitative methodologies such as grounded theory, ethnography, phenomenology before settling on case study research. The case study method has become popular for qualitative research over the past 30 years in social science, since being introduced by Yin (1984) and Eisenhardt (1989) and is now listed as one of the five major types of qualitative research (Creswell & Poth (2017) cited in Yin (2018)).

A case study allows for in-depth analysis whilst retaining a real-world perspective using case study research as the *mode of inquiry*, case studies the *method of inquiry*, and cases as the *unit of inquiry* Yin (2018:xx). I choose case study research for three main reasons; (1) my research question is a "how" or "why" question, (2) I have no control

over behavioural events, and (3) it is a contemporary, not a historical phenomenon study (Yin, 2018:2). “How” and “why” questions more likely lead to the use of a case study methodology as such questions deal with tracking operational processes and strategies over time (Yin, 2018).

The purpose of this case study is interpretive as I wish to refine existing theories and observed key concepts into the construction of a practical toolkit. However, it could also be considered evaluative as I am seeking the merit of the case (the digitalisation of construction).

Whilst case study research utilises many of the techniques seen in other research disciplines, it relies heavily on two sources of evidence: direct observation of the events being studied and interviews of the persons who may be involved in those events as it tries to consider a decision or set of decisions, why they were taken, how they were implemented and with what result (Yin, 2018).

In summary, pragmatic qualitative research is highly flexible and in effect does not require a researcher to state a philosophical or methodological orthodoxy, so therefore appropriate for a DBA. It can be useful when information is quickly needed to improve practice, such as in my study (Savin-Baden & Major, 2013). It is flexible, it allows for depth of investigation with multiple layers and multiple perspectives, it is thorough and has applicability to a wide range of practitioners. To ensure the necessary rigor, I have recorded my methodical procedures, especially the reporting of all data and evidence (Yin, 2018).

4.4.3 Other Research Methods

Consistent with a pragmatic approach, I also contemplated using other types of method before settling on case study research. As the construction sector is so vast, accounting for 13% of the world’s GDP (MGI, 2017), I first considered a quantitative or mixed methods approach, including using a survey, to obtain a wider set of views from which to extract statistical results. However, the focus of my research related specifically to new ventures and new innovation (3DCP, BIM) so I needed a more representative data set comprised of enterprises only active in this sub sector of construction. Therefore, I rejected a survey and other quantitative methods at this stage of ecosystem development based on the embryonic stage of this technology and the wide and fragmented construction industry. I decided that a typical low survey response rate of 10-20% would not add value to this research study, as the number of firms in this area is already small and would therefore be unrepresentative or useful. I choose to concentrate on purposely selected companies and key participants to

interview instead which led me to qualitative research methods. The main types are *Ethnography, Narrative, Phenomenology, Grounded Theory, Case Study and Action Research*. I rejected the first three as not suitable for this study as I did not have access to observe inside a company, this technology did not lend itself well to a historical or longitudinal study, and I was not interested in a transcendental view of the participants experience. I debated using action research as I have now founded my own 3D Construction printing company but as it is still in its gestation period and I have a limited amount of time to complete this thesis, I have rejected that approach. I will however consider further papers on my company, as I continue to keep detailed notes on its progress. This only left grounded theory as a possible complementary to case study research, as an analytical strategy, which I discuss in further detail below.

4.4.4 Grounded Theory from Case Studies

Grounded theory, questions the scientific or hypothetico-deductive method of theory verification and is defined as "*the process of data collection for generating theory whereby the analyst jointly collects, codes and analyses his data and decides what data to collect next and where to find them, in order to develop his theory as it emerges"* (Glaser & Strauss, 1967:45). One of its original tenets is that a qualitative project should begin with no knowledge of the existing theory and a researcher should begin with blank slate, before going into the field. Theories should subsequently emerge from the data itself through a detailed line by line analysis of the collected interviews and data. Subsequent papers have realised that it is impractical to believe that the researcher will have no prior knowledge of the subject before commencing a study and Strauss' subsequent work (Strauss & Corbin, 1998) now states that some appreciation of prior literature before going into the field is necessary (although Glaser still does not agree and they have not worked together since!).

The grounded theory process frequently involves the same basic analytic steps: build descriptions from the data, code into first-order codes; condense them into second-order themes or constructs; compare between the existing theories and the empirical data. It is an iterative process of data collection, progressively refining higher-order concepts to create theories that connect constructs (Eisenhardt *et al.*, 2016). Cases sampled can help reveal unusual phenomenon, replicate the findings of other cases, eliminate alternative explanations, and elaborate on the emergent theory (Eisenhardt & Graebner, 2007)

As I conducted a systematic literature review to provide priori background knowledge of the area of business ecosystems and disruptive innovation, I did not conduct a pure

grounded theory inductive approach. I was conscious not to believe I was taking a purely inductive approach when certain parts of this study has been deductive, as in the derivation of research gaps from the literature (Pratt, 2009). My literature review gave me the basis for initial questions I wanted to ask in the interviews. I also engaged in *purposive sampling*, where I used my own judgement to select companies to take part in this research study. Purposive sampling is useful when focusing on a particular subset of companies or people as they may have common interests. This allows me to get more rich data from the new ventures I wanted to research. It is distinct from *random sampling,* often seen in statistical or quantitative research, which helps to eliminate all biases from the data set (Etikan *et al.*, 2016). Purposive sampling and theoretical sampling both require an iterative process of data collection, transcribing, coding and analysis until a theoretical saturation point occurs. It is at this point that data collection stops. Saturation means that no additional data where no additional data is being found and the incremental learning is minimal (Eisenhardt, 1989; Glaser & Strauss, 1967).

Eisenhardt expanded on the grounded theory approach in *'Building Theories from Case Study Research'* to blend grounded logic with case study research (Eisenhardt, 1989). It still remains an iterative process, tightly linked to the data and is appropriate in new topic areas. For my research whilst I am not looking to add a new theory (as this is a DBA: *Theory Informed Practice*), I can still employ many of the same techniques to conceptualise a practical toolkit and so this is the main analytical approach I have taken. It allows the prior use of existing research to formulate my research question and to form initial constructs, that may or may not appear in the resultant theory, with no attempt to consider an existing theory or test any hypothesis. It uses purposive sampling of cases and multiple sources of data including my personal memos and demands an overlap of data analysis with data collection to build a toolkit from the case study. I can apply coding and pattern searching techniques to shape hypotheses through an iterative process and my emergent concepts, propositions or hypotheses can then be compared to the extant literature (Eisenhardt, 1989).

4.4.5 Single or Multiple Case

Single case studies can provide an in-depth analysis of a phenomena in the social sciences or an analysis of a particular company or situational problem. They can be pointed at both a company or an industry level and the rationale for single case research should satisfy any of following three conditions (1) the case is unusual (2) it has not been researched before, so may be revelatory (3) it can be observed

longitudinally (Ozcan *et al.*, 2017). They can be persuasive and very powerful, as only a single *talking pig* can be a significant to knowledge (Siggelkow, 2007). But if the case study analysed doesn't have a talking pig, it may end up being a case of 'who cares,' if it is not applicable outside that specific context.

In those terms it becomes just a description of a company, whereas I want to provide a conceptual toolkit with this research study. However, the problem with trying to formulate a toolkit, for disruptive companies in construction, is that it such a large industry and the technologies so new, that a single company case study is likely to be unrepresentative and therefore not generalisable to a wider population of new ventures. Case selection would also be problematic as the ventures pursuing 3DCP for example, are only at the birth stage (Moore, 2006), so many of them may not survive. This means it is a better approach to consider multiple enterprises for this study as although they may be separate entities, they are all following a similar value proposition, within the context of an industry ecosystem (Adner, 2017). These companies are small and with different business strategies which will impact the design of the case study research question and data collection and lead to an inductive approach to data collection and analysis.

A case study may contain more than a single case, typically referred to as a *single case (embedded)* design. Embedded units of analysis need to be within the original single case, as similar cases outside of the case study boundaries cannot be included. The design of this single case has to be constructed to ensure that all the embedded units of analysis are part of the same study group. When this occurs, the case study has many similarities with a multiple-case study design, which adds to the analytical robustness of the study (Eisenhardt & Graebner, 2007). By embedding these units of analysis within a single bounded case study means a more systematic approach can be followed, and researchers can be more dynamic, reacting as new data and concepts emerge (Ozcan *et al.*, 2017). This starts to resemble grounded theory from case study (Eisenhardt *et al.*, 2016). But the case study still needs boundaries and a framework.

The single case (embedded) design is therefore the most pragmatic and practical choice for my research. Whilst the design of multiple-case studies is a variant of the single case design, it still follows a logic whereby each case must be carefully selected so that they either (a) predict similar results (a literal replication) or (b) predict contrasting results but for anticipatable reasons (a theoretical replication) (Yin, 2018). In this research, it is not known if the cases will give similar results, as the companies are so new, but it also cannot be assumed at this stage that they will give contrasting results. That is why I have chosen an inductive approach and let the data guide the

findings. This approach can also apply the process of how the researcher can shift the study's focus as new concepts emerge (Ozcan *et al.*, 2017). The single case is the context of the ecosystem surrounding innovation within the construction industry with the multiple embedded units of analysis as the emerging new ventures deploying the innovations.

4.4.6 Single Case: Ecosystem for Innovation in Construction

This research is about the ecosystem surrounding innovation in the construction industry. This represents companies that are innovating in this sector as well as related actors that are intertwined or connected to the wider ecosystem that is developing in this specific area. The case study approach gives flexibility in the design of the research and the sampling of the participants. However, the strengths of case studies can also give rise to potential challenges. Firstly, intrinsic case studies dependent on the specific case risks being too narrow. Secondly, determining the 'boundedness' of a case can be difficult. Thirdly, case studies due to their flexibility and ability to draw on a number of approaches can be perceived as eclectic (Savin-Baden & Major, 2013)

To address these points: (1) this case study involves multiple units of analysis, i.e. companies; (2) Innovation in an industry sector as the boundary could be described as too wide, so the main focus is on the ecosystem boundary around two specific construction sector innovations, namely the disruptive technologies of 3DCP and BIM; (3) The research method follows a systematic approach as detailed below.

4.4.7 Single Case: Multiple Unit of Analysis

The selection of the multiple units of analysis, whilst partly being determined by access, was also driven by an interest into observing and analysing what certain companies are actually doing and not just a description of their mission.

The units of analysis are the companies involved in the ecosystems to bring disruptive innovation to the construction industry. For each unit of analysis, a set of interviews and/or secondary materials was amalgamated for comparative purposes through the use of the common thematic categories of the interview protocol. Firstly, from a descriptive stance; founder background, industry, company size, geographical location. Then an analysis of the strategies to capture value from their innovation – ecosystem type, ecosystem role, strategic partners, type of innovation and technology, open or closed innovation, stage of company development (i.e. have they built a concept house

or introduced their innovation to customers yet). This allows for a systematic approach to explore the same factors and issues for each company (Wilson & Post, 2013).

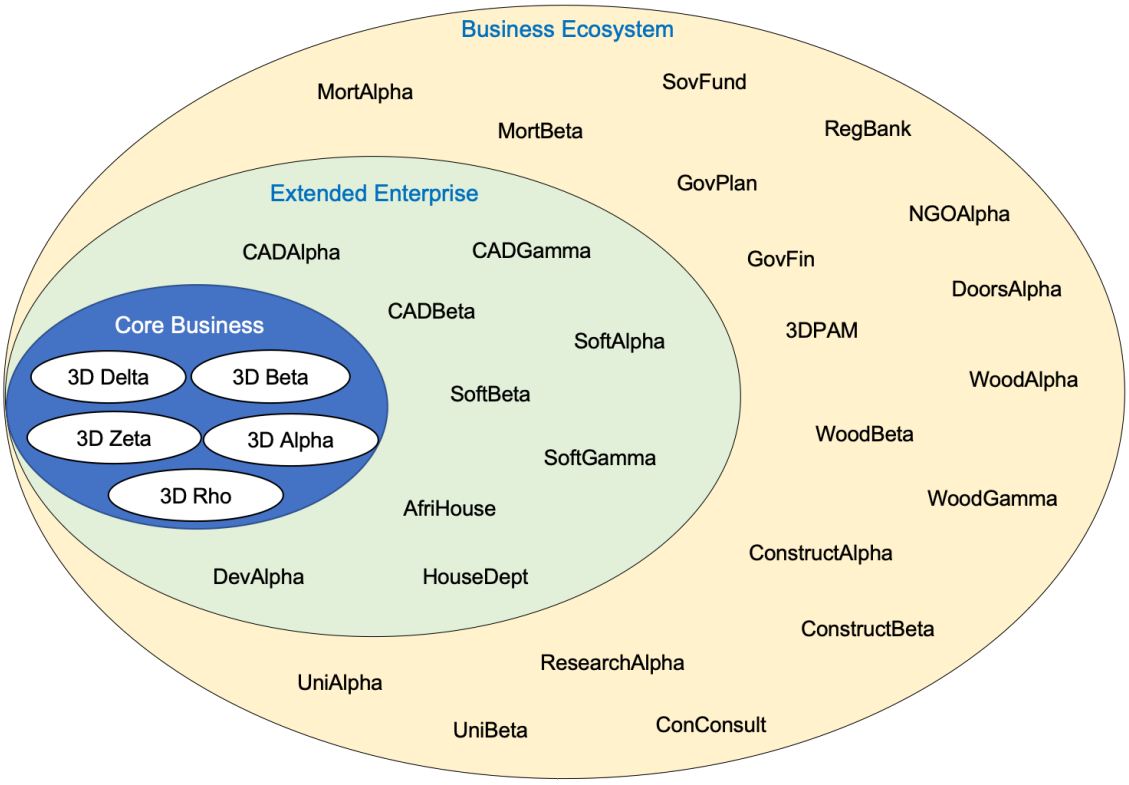
4.4.8 Selection of Cases – Innovation in Construction

A detailed description of the construction industry setting has been given in Chapter 2 Case Study above. It is a vast industry sector covering everything from small sheds to vast 25 mile bridges. To choose companies the most relevant to this research I used purposive sampling and focused on a specific subset of this industry, namely those innovating with 3DCP and BIM and their extended network of associates and partners. These companies are spread across the globe but true to an ecosystem approach, they have a common value proposition.

In purposive sampling, subjective methods are used to decide which elements to include in the sample and randomisation is not important, so all companies in a population do not have an equal chance of being selected (Etikan *et al.*, 2016). From my initial literature research into stakeholder theory and ecosystems, I identified various categories of players who are involved in the construction industry ecosystem and attempted to interview at least three players in each category of business type.

Using this purposive sampling strategy, I initially used Moore's (1996) model for layers in the construction industry ecosystem and identified the main global players in 3DCP companies to represent the core business layer of the nested ecosystem. I then conducted pilot interviews with these players to understand their connections to players in the next ecosystem layer, the extended enterprise, as well as the wider business ecosystem layer.

Refer back to Figure 3.8 Nested Ecosystem Layers for a summary of the ecosystem players which I have updated to show a graphic of companies in this study (Figure 4.3 below). Please note that I have researched many more 3DCP companies as detailed in Table 4.1 below, but for the sake of clarity I have only illustrated five as core business.



Adapted from 'The Death of Competition' Moore (1996)

Figure 4.3 Researched Ecosystem Participants

4.4.8.1 3DCP Companies

I needed sufficient access to relevant companies to interview people, review documents and records, or make field observations, using as many of the 3D Construction Printing companies as I could access as the core business. The number of companies active in 3D printing in construction is increasing exponentially with an estimated 65 currently offering a range of 3D related services (Laubier *et al.*, 2018). These companies provide services such as prototyping solutions, software and design tools, and large structural components or the construction of buildings. This research study had access to several of the pioneers in this nascent sector for primary source of data as well as collecting a large amount of secondary data from websites and company documents. I have concentrated on those that have built a printer or demonstrated the technology through a prototype.

As these 3DCP companies are not following the same strategy or business plan, I can differentiate the success or failure of their approach so therefore I have tried to sample as wide a range of companies as possible in the case study (Lee & Lings, 2008). However even this proved difficult to get more than limited access, as most of them are located in Europe or the US but I have been able to interview several main companies

as well as attend their open days and conferences, whilst having non recorded conversations with several of the other companies.

4.4.8.2 BIM Companies

From the initial pilot interviews, I was made aware of Building Information Modelling (BIM) and how it will potentially develop into an integral component part of automated construction through the use of digital twins, so I extended my research into software and process innovation alongside the 3DCP technology and I was able to interview some senior executives in this field. For BIM players I had primary access to a small number of companies actively involved in designing BIM software (which I have labelled as Construction IT), as well as many other construction ecosystem players who are currently considering their strategy to include BIM in their business plans.

4.4.8.3 Software Providers

To understand the latest computer aided, artificial intelligence (AI) and augmented reality (AR) visualisation tools available, I enrolled in online CAD software courses, totalling 30 hours of instruction. This opened up the concept of technology platforms in the initial design stage for 3DCP and its key role in the future automated construction process and led to research into the CAD software providers.

4.4.8.4 Rival Technology Companies

To provide rival explanations and concepts of introducing disruption or innovation into construction, I chose companies involved in the timber framed home construction sector, which had been considered a new innovation back in the 1980's for comparison purposes. I have interviewed senior executives in Additive Manufacturing (3D Printing) in other industries to understand their initial strategies and issues when entering their respective industries.

4.4.8.5 Other Ecosystem Players

As the construction industry is so vast, my choice of participants was deliberately varied. Casting further afield, based on pilot interviews within these sectors, I interviewed suppliers, government officials, developers and incumbent builders. I spoke to and construction consultants, universities and research bodies institutes. This allows me to gain a holistic view of the collective thoughts from a range of construction ecosystem players. This provides the case study with a range of viewpoints to the issue of innovation this industry and which strategies new ventures employ to capture value from their specific innovation.

I had hoped to also include companies involved in modular housing and the large 5 traditional housebuilders in the UK, but my attempts to gain access to their executives was fruitless.

4.4.8.6 Government Officials

Geographically, I travelled to the US and Europe to meet with the hardware/software providers. To observe the potential use of this technology in developing countries I also travelled to an African country to meet with government and senior officials to see their level of interest and understanding of how this technology could solve their housing crisis. These are potentially the end customers of the houses, built through this technology and hence I interviewed both suppliers and customers of these potential innovations.

I therefore managed to interview many current or potential future ecosystem players involved or interested in disruptive innovations that may solve the problem of housing shortage across the world. Whilst I was interviewing participants, I also became aware of other avenues for future research and although these parts of my interviews are not heavily used in this research, some snippets have been included to provide ideas on future research opportunities.

In summary I have chosen various players who deploy complimentary technologies and skills to provide a wide and diverse range of viewpoints on disruption in construction and what is required to successfully deploy it in the market.

See Table 4.1 for an anonymised list of the embedded units of analysis for which I have interviews and/or collected data.

Table 4.1 Background of Embedded Units and Data Collected

Company Name	Company Sector	Founder Background	Company Type	Location	Size	Employees	Market	Innovation	Data Collected
3D Alpha	3DCP	Technology	Private	Europe	Small	< 50	Global	Technology	Interviews
3D Beta	3DCP	Construction	Private	Europe	Small	< 50	Global	Technology	Interviews
3D Delta	3DCP	Technology	Private	USA	Small	< 50	Global	Technology	Company Documents
3D Epsilon	3DCP	Technology	Private	USA	Micro	< 10	USA	Technology	Company Documents
3D Gamma	3DCP	Technology	Private	USA	Small	< 50	USA	Technology	Company Documents
3D Kappa	3DCP	Technology	Private	Europe	Small	< 50	Global	Technology	Company Documents
3D Lamda	3DCP	University	Private	USA	Small	< 50	Global	Technology	Company Documents
3D Omega	3DCP	Finance	Private	UK	Micro	< 10	UK	Business Model	Interviews, Diary
3D Phi	3DCP	Military	Military	USA	Large	> 100	USA	Technology	Company Documents
3D Rho	3DCP	Technology	Private	USA	Small	< 50	Global	Technology	Company Documents
3D Si	3DCP	Technology	Private	USA	Small	< 50	USA	Technology	Company Documents
3D Sigma	3DCP	Technology	Private	USA	Small	< 50	USA	Technology	Company Documents
3D Tau	3DCP	Technology	Private	Europe	Small	< 50	Europe	Technology	Company Documents
3D Theta	3DCP	Research	Private	Europe	Small	< 50	Global	Technology	Company Documents
3D Var	3DCP	Technology	Private	Europe	Small	< 50	Global	Technology	Company Documents
3D Xi	3DCP	Construction	Private	Asia	Small	< 50	Asia	Technology	Company Documents
3D Zeta	3DCP	Construction	Private	USA	Micro	< 10	USA	Business Model	Interviews
3DPAM	3DP	Manufacturing	Private	UK	Medium	< 100	Global	Technology	Interviews
CADAlpha	CAD	Software	Public	USA	Large	> 100	USA	Technology	Company Documents
CADBeta	CAD	Software	Private	USA	Large	> 100	USA	Technology	Company Documents
CADGamma	CAD	Software	Private	USA	Large	> 100	USA	Technology	Company Documents
ConConsult	Construction Consultant	Consulting	Private	UK	Small	< 50	Global	Technology	Presentations
ConstructAlpha	Construction General	Construction	Private	UK	Medium	< 100	UK	Unknown	Interviews
ConstructBeta	Construction General	Construction	Private	UK	Micro	< 10	UK	Unknown	Interviews
ConstructGamma	Construction General	Construction	Public	Europe	Large	>100	Europe	Technology	Company Documents
SoftAlpha	Construction IT	Software	Private	UK	Large	> 100	Global	Software	Interviews
SoftBeta	Construction IT	Software	Private	UK	Small	< 50	Global	Software	Presentations
SoftGamma	Construction IT	Technology	Public	USA	Large	> 100	USA	Technology	Presentations
DoorsAlpha	Construction Supplies	Business	Private	UK	Large	> 100	UK	Business Model	Interviews
WoodAlpha	Construction Wood	Timber Industry	Private	UK	Small	< 50	UK	Unknown	Interviews
WoodBeta	Construction Wood	Timber Industry	Private	UK	Small	< 50	UK	Unknown	Interviews
WoodGamma	Construction Wood	Construction	Private	UK	Small	< 50	UK	Technology	Interviews
AfriHouse	Development	Business	Private	Africa	Micro	< 10	Africa	Business Model	Interviews
DevAlpha	Development	Government	Government	Africa	Medium	< 100	Africa	Unknown	Interviews
GovFin	Finance	Finance	Government	Africa	Small	< 50	Africa	Business Model	Interviews
RegBank	Finance	Finance	Government	UK	Large	> 100	Europe	Business Model	Interviews
SovFund	Government Fund	Finance	Government	Africa	Large	> 100	Africa	Business Model	Interviews
HouseDept	Government Housing	Government	Government	Africa	Large	> 100	Africa	Unknown	Interviews
GovPlan	Government Planning	Government	Government	Africa	Large	> 100	Africa	Unknown	Interviews
MortAlpha	Mortgage Bank	Finance	Government	Africa	Large	> 100	Africa	Business Model	Interviews
MortBeta	Mortgage Bank	Finance	Private	Africa	Medium	< 100	Africa	Business Model	Interviews
NGOAlpha	NGO	Charity	Private	USA	Small	< 50	Global	Charity	Company Documents
ResearchAlpha	Research	Government	Government	UK	Large	> 100	UK	Technology	Company Documents
UniAlpha	Research	University	University	UK	Large	> 100	UK	Business Model	Interviews
UniBeta	Research	University	University	UK	Large	> 100	UK	Technology	Interviews

4.5 Data Collection

4.5.1 The Case Study Protocol

A case study protocol contains a set of questions to be used in collecting the case study evidence. It also contains the procedures and general rules to be followed when using the protocol and is essential when conducting a multiple-case study (Yin, 2018). A case study protocol has four sections: (a) *an overview of the case study*, (b) *data collection procedures*, (c) *protocol questions*, (d) *an outline for the case study report*.

(Yin, 2018). The development of the protocol benefits from conducting a prior search for previous case studies as I have done through the literature review (Eisenhardt, 1989). See Figure 9.8 Case Study Protocol for the original document which later developed into my Interview Protocol.

4.5.2 Software for Data Collection

To keep a record of all articles and books gathered during my DBA research study, I used EndNote X9, Evernote and NVivo software.

EndNote X9, is a bibliographical software from Clarivate Analytics. This software stores the article's bibliographical information and its PDF in one location. During the course of this DBA I collected 1188 references, which could be used to search for keywords and to sort and group my reference material of which 246 are cited in this thesis.

I used Evernote software to capture website information and highlighted notes from books. This software links well with NVivo to import such web and book data.

NVivo is a powerful Computer Aided Qualitative Data Analysis Software programme (CAQDAS), which helps with the organisation of data for easier retrieval. In effect it is a huge filing cabinet with multiple folders for storing data and having the ability to cross reference that data. It does not duplicate the functions provided by Endnote. The use of NVivo or similar software, on any project of over 5 to 10 interviews makes the analysis much easier (Lee & Lings, 2008). Using NVivo helped me to manage data and ideas, query and visualise data and collate data in a single NVivo project which allowed me to conduct a deep analysis across all data types (Jackson & Bazeley, 2019).

4.5.3 Collecting Data

Qualitative analysis is challenging and time-consuming. Collecting data is much harder than quantitative data as it involved much liaison and arrangement with interview candidates as well as travel to various countries, including the additional expense of flight and hotels. A case should have enough data so that (a) there is confirmatory evidence from two or more different sources for the research topics (b) that evidence attempts to investigate major rival hypotheses or explanations (Yin, 2018). To be considered rigorous it will be judged by the methods of data collection and analysis procedures (Tracy, 2010). I have followed the main principles of data collection in case study research: (1) *Use multiple sources of evidence;* This is a strength of case study research (CSR) as you have the opportunity to use many different sources to validate your findings. Triangulation of data provides a more robust and convincing conclusion

or finding (Eisenhardt & Graebner, 2007). (2) *Create a case study database*; I have used Nvivo, Word and Excel software to arrange data and thereby increase the reliability of my case study. (3) *Maintain a Chain of Evidence;* I have attempted to show the steps from the deriving evidence from the initial research questions to the case study findings and outcomes (4) *Exercise care when using social media data*. This does not apply in this research case as I have not used any social media data (Yin, 2018).

4.5.4 Multiple Sources of Evidence

The main data source consists of nearly 40 hours of semi structured interviews and presentations with CEO's and senior executives of 3D printed house construction firms and other actors in their ecosystem such as government officials, NGO's, consumers, financiers, impact investors and other services such as research bodies and consultants To meet the requirements of a rigorous qualitative methodology, my approach was to triangulate data from multiple sources of information in the final thesis (Yin, 2018). See Table 4.1 above for the different types of data collected for each company. Whilst case study evidence can come from multiple sources: documents, archival records, interviews, direct observations, participant-observation, and physical artefacts, I have only used three different types of data for triangulation: (a) *Semi-Structured interviews (b) Company reports and press or website statements (c) Government and Research Institute Reports*.

As it was difficult to gain access to certain companies and their senior management, I used secondary data such as company websites, videos, articles to triangulate my findings but company accounts were unavailable due to the privacy and embryonic state of many of the companies being observed. Many of the websites had vision and mission statements as well as blogs written by senior staff members. The websites also contained information on the sponsors and partners that these start-up companies had collaborated with. Although it was not possible to speak directly to these partners, comparisons on similarities and differences could be surmised.

Thirdly, I used recent publications on government and research company websites to provide backup information on the latest wider industry thinking and initiatives to boost innovation and productivity. In line with an inductive approach I also kept an audio diary of my experiences over the data collection period to record my observations and thoughts as the research progressed. Two types of memos were recorded: (1) field notes, especially those recorded on visits to Europe and Africa to meet key ecosystem players and (2) memos of my personal thoughts and concepts as part of my theorising.

Once any relevant information was transcribed into Word documents these were subsequently imported into NVivo to be coded alongside the transcripts if deemed important.

4.5.5 Semi-Structured Interviews

4.5.5.1 Interview Participants

Case study interviews are the most important source of data in this research. A good rule of thumb is that at least 20 interviews are necessary for theory development (Lee & Lings, 2008). This research consisted of 30 interviews consisting of 32 hours of recorded interviews conducted over 12 months between Dec 2018 and Dec 2019 supplemented with 10 relevant recorded presentations by key industry players (7 hours) as illustrated in Table 4.2 below. Attention has been given to the seniority and job description of the interviewees to prevent biases in the data collected (Eisenhardt, 1989). My approach was to use many highly knowledgeable informants who see the research topic from different perspectives, i.e. from different levels of seniority, functional areas, geographical location and range of companies as well as external industry observers (Eisenhardt & Graebner, 2007). The range of ecosystem players interviewed definitely stretched the data diversity. Where possible I interviewed the founder or co-founder of an enterprise to get his perspective on the company's mission and intention, but it is also important to include other key personnel for their views, which do not always tally (Wilson & Post, 2013).

As my context was disruptive technology in the construction industry, my interviews were conducted with a variety of ecosystem players who I considered important in the establishment of a new technology. Interviewees then gave me contacts or their thoughts on other significant ecosystem players which expanded the scope of my analysis. I carefully selected the firms and the level of seniority of the interviewees in those firms, to give me a good yet in effect randomised selection of ecosystem players (Eisenhardt *et al.*, 2016). I deliberately did not target one company and their partners as I wanted an overall viewpoint, not just a single case study. However, the construction industry is a broad umbrella covering everything from garden sheds to superhighways, so this research recognises the limited nature of the study compared to the massive size of this $10 trillion industrial sector.

As I wanted to look into the context of new technology across different countries, I purposely targeted an African country as a focus. This was mainly because I had

researched their housing shortage and also because I had access to very senior Government officials in that country.

Table 4.2 Summary of Interviews

Company	Minutes of Audio	Pages of Transcripts	Number of Interviews	Number of Interviewees	Interviewees Role
3D Alpha	580	307	10	3	CEO, CTO, Communications Director
SoftAlpha	262	182	5	6	Chairman, CEO, CTO, COO, Group Commercial Director
ConstructBeta	127	93	1	3	2 Founders, Director
3D Beta	120	77	1	2	CEO, Strategic Advisor
ConstructAlpha	112	47	1	5	CEO, 4 Directors
UniAlpha	97	43	2	2	Research Professors
DoorsAlpha	91	41	1	1	CEO
3DPAM	71	33	1	1	CEO
MortAlpha	65	27	1	1	Director
WoodAlpha	63	28	1	1	CEO
GovFin	60	28	1	1	CEO
SovFund	60	18	1	1	CEO
HouseDept	60	22	1	9	Dept Head, Deputy Head, Engineer and Directors
MortBeta	60	29	1	1	Director
3D Zeta	57	27	1	1	CEO
AfriHouse	56	26	1	1	Founder
RegBank	54	28	1	1	Principal Banker
WoodGamma	50	38	1	1	CEO
SoftGamma	45	13	1	2	CTO, Digital Officer
WoodBeta	44	20	1	1	CEO
UniBeta	39	20	1	1	Research Professor
3D Omega	37	18	1	1	International Sales Director
ConConsult	35	10	1	1	Director
GovPlan	30	7	1	1	Dept Head
SoftBeta	27	8	1	1	Director
DevAlpha	23	9	1	3	General Manager, Asst GM, Surveyor
Total	2325	1199	40	52	

4.5.5.2 Interview Protocol

Semi-structured interviews are useful as I had already established a clear theoretical appreciation of the research area from my systematic literature review. This allowed me to construct an interview protocol guide with general themes and related questions. This guide served as a memory prompt and helped the interview or discussion flow in an ordered and consistent manner (Lee & Lings, 2008). Pilot interviews held with several companies and ecosystem players helped refine the semi structured interview questions (Wilson & Post, 2013). Various iterations of interview questions were tried, starting with a template from Brennan (2015) and then modified to incorporate feedback from the pilot interviews and my supervisors, as well as focus on the themes for this research study (Eisenhardt, 1989).

The interview question protocol was deliberately designed with a range of themes to be presented to interviewees rather than a systematic rigid order of questions. The themes provided the semi-structure of the interviews, but the range of prompting questions per theme could be altered to keep a flow and open dialogue during the interview (Savin-Baden & Major, 2013). This allowed me to let the interview be guided

more by the interviewee, all very senior company people, so that a rich data set emerged.

The Interview Question Protocol was used during all the interviews. It consists of an Introduction (repeating the purpose of the research), Aim, Process and Output expected of the study, Explanation of the Interview Process, Potential Interview Themes and Questions: *(1) Participant Background (2) Key stakeholder relationships, (3) Business Ecosystem, (4) Ecosystem Strategy, (5) Disruptive Technologies*. There was also an Observation Protocol to record Attributes for NVivo based on Savin-Baden and Major (2013). See Figure 9.9 Interview Protocol and Figure 9.10 Interview Questions.

In addition to the initial stakeholders and ecosystem themes, the interviewees were asked questions regarding disruptive technologies, as the research is interested in the cross connections between the two. Business model was not explicitly questioned but was frequently referred to by participants. I intentionally did not discuss disruptive innovation or technologies until the end of the interviews in order to eliminate bias and to allow the participant to speak more now they were comfortable. I found this gave more insights into their thoughts and the interviews revealed other disruptive technologies and innovations currently emerging in the construction industry.

The interview protocol also allowed for new ideas and themes to be discovered, some of which were useful for this research study, whilst also highlighting avenues for future research.

4.5.5.3 Interview Technique

My interview technique developed as I progressed in the data collection, but after the first initial test interviews I was consistent in my approach. I would always try and conduct a face to face interview if possible, even if this meant travelling across Europe and Africa. The locational context that this provided was useful in the data. Most interviews lasted approximately 1 hour but I was fortunate to have longer access time with several key players in this industry, with some participants kindly indulging me for 2 hours in one sitting and then with follow up interviews.

4.5.5.4 Transcripts

All my interviews were fully transcribed to capture as much of the exchange as possible. "*At the very least, if another person produced the transcripts, it is absolutely essential for the person who did the interview to review and edit the transcript while listening carefully to the recording*" (Jackson & Bazeley, 2019:42).

All the interviews were transcribed verbatim with time stamps and speaker names by *rev.com*, a respected third-party transcription service provider, under a strict confidentiality agreement. Verbatim transcripts provide a full, rich record of the interview to ensure no data or inference has been missed. All transcripts were anonymised before being stored at the University of Warwick but may be destroyed after 10 years in accordance with the University's policies and guidelines.

To ensure the accuracy of the transcriptions outsourced to *rev.com*, I listened again to all the audio recordings and used the music industry software *Reaper* to enhance audio quality, especially for those conducted in larger conference rooms with multiple participants. Corrections were made to all the transcripts, as even a single missing word can alter the meaning of a sentence. This took 120 hours to review and correct the 40 hours of recordings.

I have kept a copy of the original audio recordings, the original transcription by the company *rev.com* as well as the revised transcripts that have been used in this research. I also recorded the *Attributes* of the interviews such as location, setting, participants clothing for use in further research studies if required (Lee & Lings, 2008)

4.5.6 Secondary Data

Secondary data came from Company reports and press or website statements and Government and Research Institute Reports. Company reports mainly consisted of websites data and press releases, but actual company accounts were not available due to the private nature and micro size of most of these companies. Government reports from the HM Government or Office of National Statistics and research publications from large consultancy firms such as McKinsey, Deloitte or Planning, BIM and Construction Today were used to provide extra information on the latest initiatives and status of the innovation in construction today. These reports are freely available for download. I stored these reports in pdf or in Evernote, with relevant sections being imported into NVivo if required.

Use of memos is commonly associated with grounded theory, yet all qualitative studies can be enhanced by their use (Birks *et al.*, 2008). I recorded an audio diary using Otter.ai during the research period, which were imported into NVivo as transcribed memos for potential coding or used for concept generation. This provided a record of my own thoughts to focus the study towards providing solutions to the problem.

4.6 Data Handling

All interviews were conducted in accordance with the ethics guidelines set down by Warwick Business School. A yearly review of any ethical considerations in my research was conducted using the Research Ethics Form and Checklist. See Figure 9.12 Research Ethics Checklist.

4.6.1 Communication Prior to Semi-structured Interviews

Prior to every interview being conducted participants were given an introduction to the research study in the form of the Interview Protocol word document. This highlighted the project synopsis, the intended interview process and themes of the questions. Any questions the interviewee had were answered prior to the recording device being activated and the interview commenced. See Figure 9.9 Interview Protocol

4.6.2 Consent and Right to Withdraw

All interviewees were presented with a Consent Form prior to the commencement of the interview. This form was in accordance with the guidelines set by Warwick Business School and required the interviewee to initial (or tick) their understanding for the following topics:

All interviewees were made aware of the voluntary nature of their participation in the research study and how the information was to be processed and stored. They were informed of their right to withdraw at any time. They were made aware of the recording devices being used for the interviews which was kept in plain sight at all times. They were explicitly asked if they gave permission to be recorded and a conscious effort was made to show the start and end of the recording.

The sole purpose of the interviews was to help complete this thesis and the writing of any associated academic journals.

All interviewees were asked to sign and date the Consent form along with the signature from the Researcher. These have been scanned into a password encrypted folder. See Figure 9.11 Interview Consent Form

4.6.3 Anonymity and Confidentiality

All interview participants and company names have been anonymised. Whilst this research study does not relate to highly sensitive personal data, it does contain organisational details of their companies' processes, strategies and the interviewees

personal opinions about the strategies of their competitors. It also details their own visions for the introduction of disruptive innovations in their field. As such this information could affect their competitiveness if these individuals or their companies could be identified. Therefore, generic names were used for both the interviewee and for their company identifiers discussed below. Interviewees were asked if they would like to receive a copy of the verbatim transcript, yet not one participant made this request. It remains their right to see a copy of their transcript at any time in the future.

4.6.4 Interview Participant ID and Attribute Information

All participants were anonymised using a generic labelling system. Interviews started with 'I' then a number and was numbered chronologically according to the date in which the interview was conducted, so the first interview conducted was I01, the second I02 and so on. Conference presentations were similarly coded with 'P' then a number such as P01, P02... Interview Participants were similarly numbered in a chronological order, I001, I002... allowing for multiple participants in an interview to be individually identified.

Companies were anonymised using a combination of industry sector and a generic Greek alphabet code. For a 3DCP company the code started 3D then Alpha, Beta, resulting in 3DAlpha, 3DBeta…3DZeta. For Timber construction industry WoodAlpha, WoodBeta. For IT companies SoftAlpha, SoftBeta and so on.

To ensure traceability through the data a spreadsheet was constructed with data pertaining to each interview.

Interview ID, Participant ID, Company, Company Type as the first data columns allows for fast tracking of data. Subsequent data included Date, Time started, Time (mins) or any other attribute information that was coded into NVivo.

4.7 Data Analysis

4.7.1 Summary of Data Analysis Process

The data analysis consisted of an iterative process of collecting data, multiple rounds of coding based on initial propositions and inductive concepts leading to a set of key findings from which a practical toolkit was formulated. This has been illustrated in Figure 4.1 above.

After collecting the data, the first major analysis concerned data reduction, "*the process of selecting, focusing, simplifying, abstracting, and transforming the data*" (Miles & Huberman, 1994:10). The raw data from the interviews and secondary material was

converted to ‘analysable form’ through transcribing, coding, interpretive analysis and contextual inference.

Multiple rounds of coding reduced the data into a smaller number of themes or concepts from which my toolkit could be developed. It is probably the most widely employed method and whilst it can be done manually, I used Warwick University’s version of NVivo 12 for Mac for the reasons above (4.5.2 above). One immediate distinction is to understand the difference between codes and themes. A theme is an outcome of coding and categorisation, but it is not a code itself. The definition of a code is *“most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data.*” Saldaña (2015:4).

The first rule when coding is not to jump to conclusions, instead let the data provide the initial themes whilst you explore, contrast and compare (Jackson & Bazeley, 2019). It is an iterative process and the period of initial coding was followed by a review and subsequent revision in a second cycle of coding. My time coding and analysing the data was consistent with previous estimates of at least 3-5 hours per hour of transcript (Jackson & Bazeley, 2019; Miles & Huberman, 1994). Once I had coded enough transcripts to generate convincing answers, I had reached data saturation.

The analysis of the data, was done using guidelines suggested by practitioner books (Jackson & Bazeley, 2019; Richards, 2014; Saldaña, 2015). I was careful to avoid ‘over-interpreting’ the data to ensure that any finding or result was plausible through data verification rather than a personal intuition. As Strauss and Corbin (1998:47) declared: ‘*Insights do not happen haphazardly; rather they happen to prepared minds during interplay with the data*.’

4.7.2 Iterative Coding Method

Selecting the most appropriate Coding method depends on alignment to the research question. Saldaña (2015) lists 33 different types of coding that can be used in qualitative research. However, I followed his advice for novice coders to start with a combination of basic coding methods that are consistent with the Strauss and Corbin (1998) three-step coding technique: initial coding, axial coding and final categorisation into major themes. See Table 4.3:

Table 4.3 Typical Novice Coding Styles (Adapted from Saldaña, 2015:73-74).

1st Round Coding	**Description**
Descriptive Coding (for notes, documents)	Descriptive codes are usually a short word or phrase to describe a document, field note or data. It provides an inventory of topics for indexing (Saldaña, 2015).
Attribute Coding (for Attribute descriptions and Values)	*Attributes* are descriptions about the interviewee, job description, nationality, gender, clothing, interview location.
Structural Coding (For the overview)	Structural Coding applies a conceptual phrase or topic of inquiry to a segment of data to both code and categorise. These codes are generally the foundation work for further detailed coding
Conceptual Coding (For concepts emerging from the data)	A concept is a bigger picture view. You can touch a clock, but 'time' is the concept. Disruption and innovation are concepts.
Initial Coding (for interview transcripts)	Initial coding reduces qualitative data into various parts, examines them, then analyses them for similarities and differences (Strauss & Corbin, 1998).
2nd Round Coding	**Description**
Eclectic Coding (for refining first cycle choices)	Eclectic codes are used to refine first round codes into a more unified scheme. It allows a researcher to combine similar yet initially independent codes into a more structured singular code.
Pattern Coding (categorisation for initial analysis)	A Pattern code identifies similarly coded data. This develops major themes from the data and categorises them for initial analysis. Pattern matching takes a significant amount of time and many iterations
Axial Coding (how categories relate to each other)	Axial Coding explores how the categories and subcategories relate to each other. Describes a category's characteristics and the location of that characteristic along a range whilst exploring how the categories and subcategories relate to each other.

Using NVivo allowed me to search for patterns through the data and represent the codes graphically which I then condensed down and manipulated into a thematic framework from which I could let my initial toolkit ideas formulate. Constructed codes form into categories, categories (or concepts) into themes and themes into a toolkit. See the illustration Figure 4.4 adapted from (Gioia *et al.*, 2013) and (Saldaña, 2015) which is similar to the approach of recent researchers studying ecosystems (Dattee *et al.*, 2018).

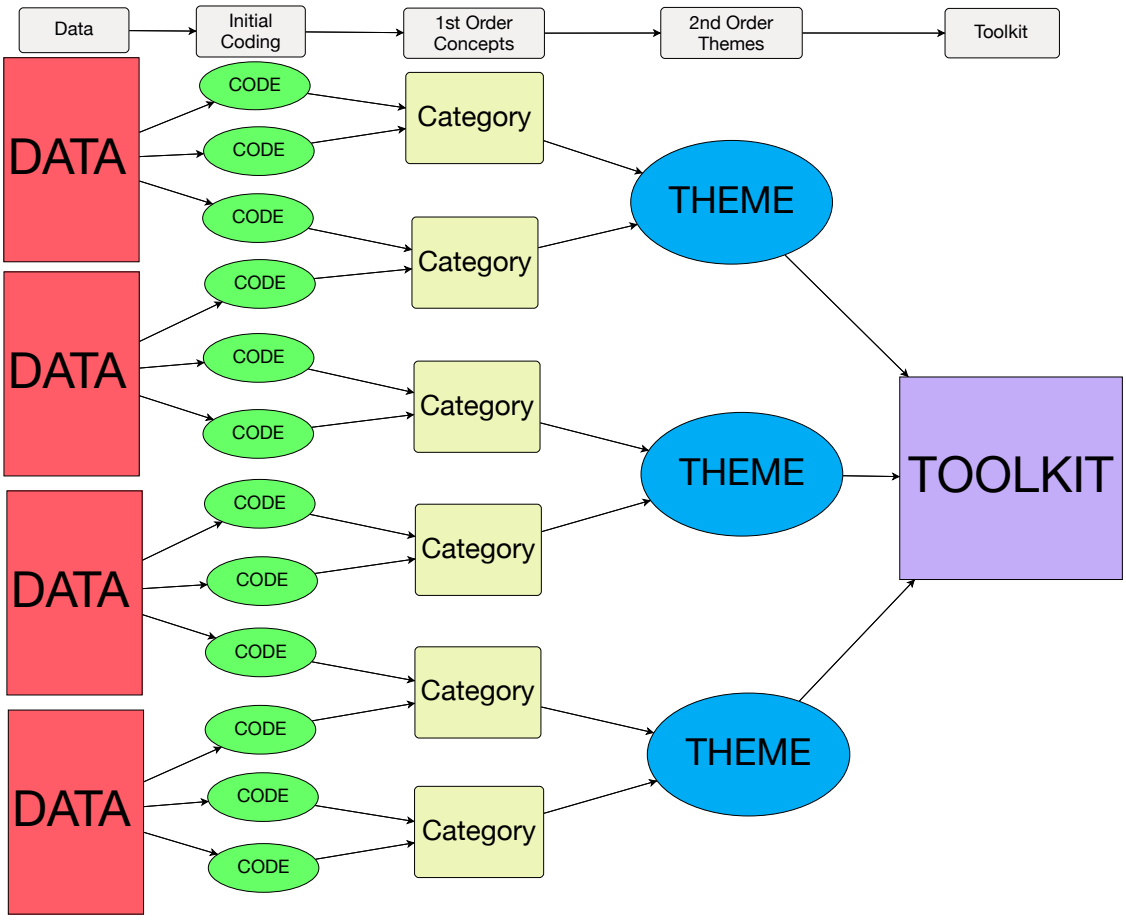


Figure 4.4 Qualitative Codes to Toolkit (Adapted from (Gioia et al., 2013:21, Fig 1) & (Saldaña, 2015:14, Fig 1.1)

4.8 First Round Coding

4.8.1 Initial Coding

Initial coding reduces qualitative data into various parts, examines them, then analyses them for similarities and differences (Strauss & Corbin, 1998). A multitude of attributes, codes, and categories emerge in a 1st-round analysis, with the number of categories easily 50 to 100 emerging from the first interviews which can be overwhelming (Gioia

et al., 2013). By 'lumping' or 'bucket' coding, my initial task was to 'chunk' the text into more general topic areas, to take one pass through the data with a number of initial codes before a more detailed second coding pass through. I used this approach, beginning with my starting concepts, to see whether answers to my research question could be developed out of the broad themes from the existing literature that I applied to the data (Jackson & Bazeley, 2019).

When reviewing a passage of text or transcript, (1) Identify and Record: What's interesting? (2) Ask Yourself Why: Why is it interesting? Make a note or a code (descriptive or interpretative), (3) Explain Yourself: Why am I interested in that? Is there a concept that interests you? Code it. Richards (2014:88).

As I was not experienced in coding, I used journal articles as a pilot practice test for lump coding before using the transcripts. I choose Eisenhardt's *Building Theory from Case Study Research* (1989) and James Moore, *Predator and Prey* (1993). For Eisenhardt, even this 20-page article delivered 16 initial Nodes: *Definitions, Research Methods, Strengths, Weakness, Theories, Data Analysis, Good Quotes, Practical Toolkit, Research Roadmap, Theory Development, Existing Literature, Case Study, Cases, Saturation, Shaping Constructs, Usefulness*.

For Initial Coding it is wise to keep the number of codes to a manageable level. Codes were given an easy to understand name and I tried to keep the number to below 40, so that I could see the hierarchical structure on a single page. After adding codes from the Moore article, I had 42 codes. From just two articles! So be careful not to let codes go viral. Once I had learnt the basics of how to use NVivo to generate codes for the first two journal articles, I repeated this for all the 86 literature review articles as well as 11 research methods articles.

I then repeated this process for the transcripts of interviews and presentation. This comprised of 1199 pages of transcripts from approx. 32 hours of interviews and 7 hours of presentations (2325 minutes).

It took 200 hours to complete the initial coding of both articles and transcripts and get close enough to the data to find interesting patterns. So unlike the perception held by some students, coding is not an easy option when comparing the choice of quantitative vs qualitative research methods (Lee & Lings, 2008).

4.9 First Round Analysis

4.9.1 Coding Literature Review Articles

Although not widely used amongst my peer group, I found NVivo helped my literature review by facilitating searching, coding, memoing, writing and analysis of the literature.

I used NVivo to filter and condense the SLR articles into relevant codes and I could then use its sophisticated coding and querying functions to understand the gaps and relevance to my research question (Jackson & Bazeley, 2019). By also storing my own notes within NVivo these could be connected to the other collected data files. I found this especially useful to easily search for key relevant passages when returning to the original, relevant material.

I used my Excel spreadsheet of extracted data (Table 3.2 above) to guide the order in which I read through the articles for coding. I did this as I believed the articles ranked highest and most important, in my view, would allow a better Initial Coding that I could use to 'lump' text into, before a second cycle would reduce this down to 3-6 key themes without allowing a spreading viral coding.

By highlighting gaps in the literature, I generated questions from collating and coding the texts, and kept separate folders for relevant and non-relevant material to help define the boundaries of my research question. This helped formulate the initial propositions shown in Section 4.3.2 above. I constructed a vista code structure to enhance my literature review with codes on *definitions, theories, research methods and related subgroups* (Jackson & Bazeley, 2019). This allowed me to select pertinent articles to be compared and contrasted with the interview transcripts, rather than just being a summary of existing literature (Bloomberg & Volpe, 2008). The end goal was to identify gaps that could be researched, and to add to the extant body of knowledge. I spent approximately 100 hours coding the review articles with each one taking approximately one hour to code. My coding structure provided 59 initial codes from which I was able to identify relevant themes for this literature review and subsequent analysis against my collected data set (See Table 4.4). The initial number of codes and selected passages from each article was wide ranging with (Overholm, 2015): 17 Codes and 100 References (extracted data) down to (Rafii & Kampas, 2002):1 Code and 2 References (Figure 4.5). These 59 codes considerably aided the writing of the literature review and methods. For the findings and outcomes chapters, a subset of 25 codes were used in conjunction with the transcript codes for analysis against previous research.

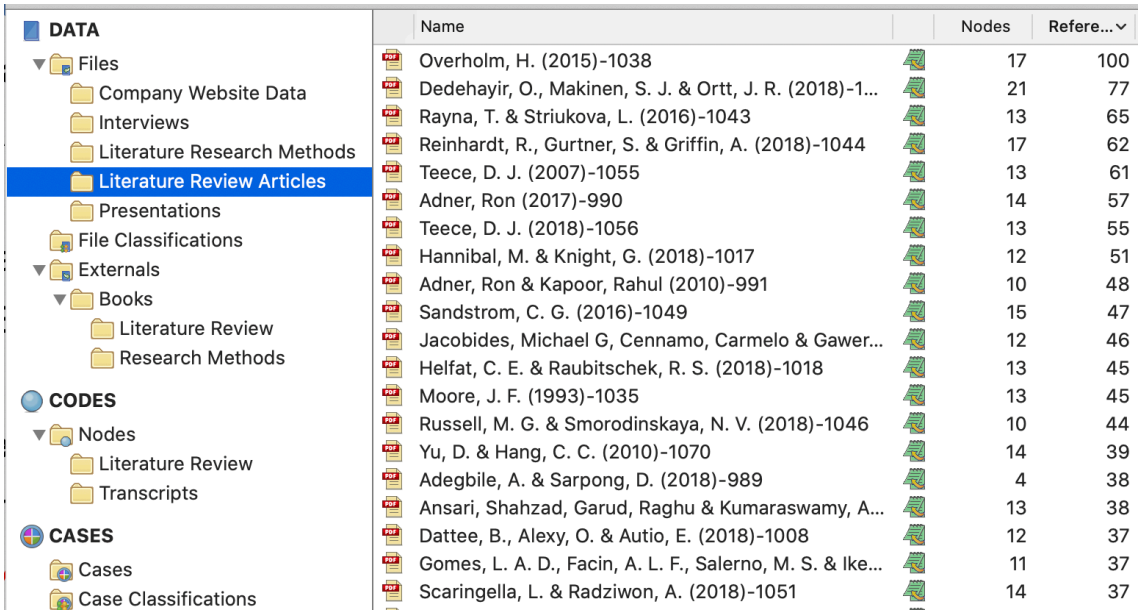


Figure 4.5 Example of NVivo List of Articles with Nodes and References

Visualisation tools such as Maps (both Mind maps and Concept maps within NVivo 12) helped explore questions and focus ideas for my research direction, of which several are shown in the Appendices (Figure 9.4 to Figure 9.7). For both the literature review articles and transcripts, I constructed code tables to illustrate the number of references (extracts) in each code, the number of codes in each theme and for the Findings, examples of good quotes in each code (Ladd, 2017; Miles & Huberman, 1994). See Table 4.4 and Table 4.5.

Table 4.4 Initial Literature Review Codes

Layer	Name	Files	References	Description
1	Good Quotes LitRev	68	250	Good Quotes from the literature review that can be found easily
1	Definitions	54	167	Any Definition of anything in the literature reviewed
1	Practical Toolkit	34	146	Anything from the literature or interviews that could be useful for a toolkit
1	BoP or Low End	16	71	Base of Pyramid or Low-End Context
1	Limitations or Gaps	33	63	Anything missing from the research studies and their highlighted gaps to point to future research areas
1	Value Creation	22	57	Anything related to Value Creation
1	Good Quotes Methods	12	49	Anything useful for my methods section write up
1	Focal Firm or Platform Leader	15	44	Is this company in the centre of its ecosystem, a keystone player
1	Weaknesses & Challenges	16	37	Any weaknesses or challenges seen in the literature
1	Value Capture	11	25	As opposed to Value Creation
1	Leadership	13	23	All aspects of leadership in context of the literature research
1	Case Study Research	10	21	Case Study Research. Definitions, uses, mentions in the literature
1	Data Analysis	11	19	How to analyse the data collected. Various methods described
1	Cases	11	15	The cases used in the literature and industries studied
1	Affordability	1	3	Low Cost, Affordable
1	Social Entrepreneurship	2	3	What is it, how can this research be used
1	Research Methodology	0	0	Main Heading - No Codes
1	Strategy	0	0	Main Heading - No Codes
1	Technology	0	0	Main Heading - No Codes
1	Theory	0	0	Main Heading - No Codes
2	Ecosystems	48	230	Anything on ecosystems and the theory of ecosystems
2	Disruptive Innovation	56	195	All mentions of DI theory in the literature
2	Research Methods	36	138	Any technique or method used for research
2	Business Models	32	100	Business Model or anything related to that
2	3D Printing	15	67	Any mention of 3D printing or 3D construction printing
2	Dynamic Capabilities	18	58	DC theory, ambidexterity
2	Collaboration	19	48	How individuals and firms collaborate, share, co-create
2	Open Innovation	15	33	Anything to do with open vs closed innovation approach. Based on Chesbrough
2	Bottlenecks	10	29	Any choke point, bottleneck or barrier seen
2	Competition	11	23	How do firms compete. What are their views on each other?
2	Network Theory	9	18	Networks as distinct from alliances or ecosystems
2	Systematic Literature Review	5	12	Methods for conducting a SLR
2	Resource Dependency Theory	9	10	Theory
2	Competitive Strategy	7	9	Theory
2	Theory Building	3	8	How to use applied research to build theories
2	Alliances	5	7	Alliance Theory, distinct from Networks and Ecosystems
2	Institutional Theory	5	6	Theory
2	Transaction Cost Economics	4	6	Theory
2	Grounded Theory	4	5	Anything to do with the grounded theory approach to research
2	Research Question	4	5	Definition and construction of a research question
2	Opportunity Theory	1	3	Theory
2	Stakeholder Theory	2	3	Theory
2	Research Roadmap	1	2	Road map for research
2	Shaping Constructs	1	2	How to start ideas about theoretical constructs and hypotheses
2	Saturation	2	2	Theoretical Saturation and end of data collection, data iteration and analysis
3	Incumbent Firms	32	111	Anything related to incumbent firms as opposed to new entrants
3	New Ventures	34	96	Not incumbents. Start-ups
3	Platforms	23	50	Any digital or industrial platform seen
3	Stage 1 Birth	10	39	Moore's Theory
3	Roles	5	18	Descriptions of the different roles taken in an ecosystem
3	Cluster	3	11	Cluster theory specifically around innovation or knowledge ecosystems
3	Knowledge Ecosystem	3	9	As distinct from other ecosystem types
3	For Benefit	1	7	B Corps with a dual or hybrid purpose
3	Stage 3_Mature	3	7	Moore's Theory
3	Frugal Innovation	3	6	Frugal, Low-End or BoP related innovation
3	Stage 4 Death	2	6	Moore's Theory
3	Strengths	2	4	For Theory Building
3	Stage 2_Expansion	3	4	Moore's Theory
3	Existing Literature	1	2	For Theory Building
		14	43	Average

4.9.2 Initial Transcript Codes

The systematic literature review articles coded in Nvivo helped formulated the initial propositions by illuminating areas that I wanted to explore and exposing gaps in the existing knowledge. Using the codes generated I narrowed this down into an initial set of six major First Order Concepts which could also serve as the basis for my interview protocol. These I classify as my six Initial Master Codes: *Attitudes*, *Company Initial*

Stage, *Disruptive Innovation & Technologies*, *Environment (VUCA)*, *Perception of role in Ecosystem*, *Strategy*.

Using the same methods of first round coding for coding the literature articles, I used an inductive approach to code the transcripts of the interviews and presentations. The initial coding was consciously done to distill data into different codes but without deep analysis of each line, in an attempt to avoid my ranking of the importance of the data stemming from any initial preconceived thoughts. This led to an additional 56 codes with the number of references within each code (Figure 4.6 Initial Transcript Codes and 1st Order Concepts). Obviously as the study used semi structured interviews, these can be considered as Sub Codes to the initial Master Codes or *Categories*. I acknowledge that further research could be undertaken to build on this study and may result in additional categories, themes or concepts to emerge but the strategy here was to use the initial concepts in a semi structured interview to lead to new insights and a rich data set along a focused area of discussion.

In effect these *Sub Codes* (DI-3DCP, DI-BIM, Proof of Concept, Positive, Negative...) provide a more detailed subset of data as well as *Antecedent Codes* (Background, Image Problem…) and *Consequence Codes* (Vision, Being Disrupted, Collaboration…) to the initial First Order Concept or Master Codes.

Table 4.5 Initial Transcript Codes

Construct	Layer	Name	Files	References	Description
BARRIER	2	Standards Regulations Bureaucracy	30	180	Any Observation about building regulations, industry standards, existing bureaucracy in their business
BARRIER	2	Construction Industry	24	176	Observations about the Construction industry
BARRIER	2	Competitors Thoughts and views	21	164	Observations and thoughts on the competitive market, competitors actions and abilities
BARRIER	2	Bottlenecks and Barriers	29	150	What is stopping the growth or their market, what keeps incumbents safe from new ventures?
BARRIER	3	Risk of adopting new tech	20	109	What are the risks of investing in a new technology
BARRIER	4	Perception of Africa and Asia	18	87	What do people think about Africa, Asia, new markets?
ECOSYS	2	Stakeholders and Partners	34	226	Any observation on a partner or stakeholder in their ecosystem
ECOSYS	2	Collaboration	25	98	Any observation on collaborations, co-creating, working with other for a common goal
ECOSYS	2	Central or Peripheral Player	14	61	Are they a keystone player or a peripheral player in their ecosystem
ECOSYS	2	Open or Closed Innovation	19	53	Chesbrough and his open innovation theory. Any observation on open vs closed
ECOSYS	2	Keystone Player	11	48	Following from Iansiti - Who is the keystone player? What attributes do they have?
MARKET	2	Benefits Potential Efficiency	33	247	Customisation, Speed, Efficiency
MARKET	2	End Customers perceptions	26	210	Any observation or requirement from potential end customers of new technologies.
MARKET	2	Cost of new technology	23	114	How much does it cost to invest in these technologies
MARKET	2	Cost Quality or Design	16	87	What is the most important variable for people to get excited/involved with any new technology?
MODEL	2	Vision_Who are We	33	206	Any comments on company direction, end goals, values
MODEL	3	Business model innovation	27	164	Any observation related to business model rather than technology innovation
MODEL	3	Being Disrupted	26	105	Observations on how construction is being disrupted
MODEL	3	DI_BIM, Digital data	16	95	BIM is Building Information Management What is the interviewees understanding of BIM
MODEL	2	Innovation Technology or business model	6	55	Is the innovation actually driven by the technology or other things?
MODEL	3	Productivity	8	20	How can you measure the new vs old technologies. Productivity, metrics
NOTICED	2	Positive, Interesting	37	174	Positive expression, excitement, interested
NOTICED	2	First steps to be first	26	157	What did companies do to help create a market for their goods?
NOTICED	2	Proof of Concept	29	138	Anything related to a prototype or Proof of Concept
NOTICED	2	Hype	13	85	Any hype or over promising
NOTICED	2	Influencers & Pioneers	16	73	Who are the influencers and pioneers in these technologies? Any observations about them
NOTICED	2	Training and Support	20	69	Any observation on support, training needs and development of people, awareness of operating the equipment
NOTICED	2	Marketing needs and issues	9	55	What marketing strategy do you employ?
TECH	3	Overcoming Technical issues	18	130	What are the technical issues, how are they being addressed?
TECH	2	Technology of its time	16	72	Is it an old tech but now ready for the market?
TECH	2	Evolution or Revolution	15	58	Is the technology an evolution or a revolution?
TECH	2	Complimentary Tech and model	12	47	Do technologies have complimentary technologies?
	2	Negative, Hard, Difficult	29	173	Negative comments, feeling of difficulty, hard to achieve
	2	Backgrounds_ Black Sheep maybe	26	145	Background of interviewees, their traits, education
	3	DI_3DCP	17	106	3D Construction Printing
	3	Mortgage Market	6	87	Observations on the requirements for a mortgage and criteria necessary to start a mortgage market
	3	DI_Materials	16	84	Materials Science and development
	3	DI_Timber technology	9	65	Timber Construction, GluLam, Cross Laminated Timber (CLT)
	3	DI_Modular Housing PPVC	15	63	Modular Housing or PreFormed, PreFinished Volumetric Construction (PPVC)
	2	Financing	7	63	How will people afford this disruptive technology?
	2	Monitoring	13	50	How do you monitor the market and your competitors?
	2	Software	6	48	General comments about software, not directly related to an individual system or technology
	2	Platforms	13	43	Any observation about emerging platforms for technology
	3	Cheap and fast, fail early fail fast	8	38	Observations specifically on testing of products
	3	Grants and Seed Capital	7	31	Anything that was related to start-up funding of the company
	2	Trust	10	28	Any comment on trust, loyalty, wariness of proceeding without knowing the partners
	3	DI_3DP	6	25	3D Printing
	2	Troubleshooting and capabilities	2	24	How to deal with issues in projects
	3	Other New Technologies	5	16	Sub Code - Any other tech not in already in a code
	2	Neutral	8	13	Neither positive nor negative, but an observation
	2	Adoption	4	11	Any observation about how to adopt new technology
	2	Ecosystem Evolving	4	11	Is the ecosystem around them evolving over time - The 4 stages from Moore
	3	Image problem	4	11	What image does construction have
	2	Consultant Partner	4	9	Main partnership specifically that of a consultant
	3	Passive House	2	8	Huf Haus, highly insulated pre constructed modular houses
	1	Attitude	0	0	Main Heading - No Codes - Any emotion or attitude seen in the interview
	1	Company Initial Stage	0	0	Main Heading - No Codes - Anything related to how these companies started
	1	Disruptive Innovation and Technologies	0	0	Main Heading - No Codes - Anything with disruptive innovation or technology
	1	Environment (VUCA)	0	0	Main Heading - No Codes - What is the business environment that these new technologies are being launched into
	1	Perception of role in Ecosystem	0	0	Main Heading - No Codes - Do people recognise their place in the ecosystem surrounding them?
	1	Strategy	0	0	Main Heading - No Codes - What is the strategy?
	2	Types of Technologies	0	0	Sub Heading - No Codes - Any type of technology as sub code
			16	88	Average

I spent approximately 300 hours to prepare, conduct and code the interviews. In each Initial code there was an average of 88 references (extracts) from the transcripts ranging from 245 for Benefits, Potential, Efficiency code down to 8 for Passive House code. In common with other researchers findings, these extracts were not randomly distributed across the interviews; some respondents touched on several different ideas that proved to be common across the sample, whereas others discussed experiences that were not found in other interviews (Ladd, 2017).

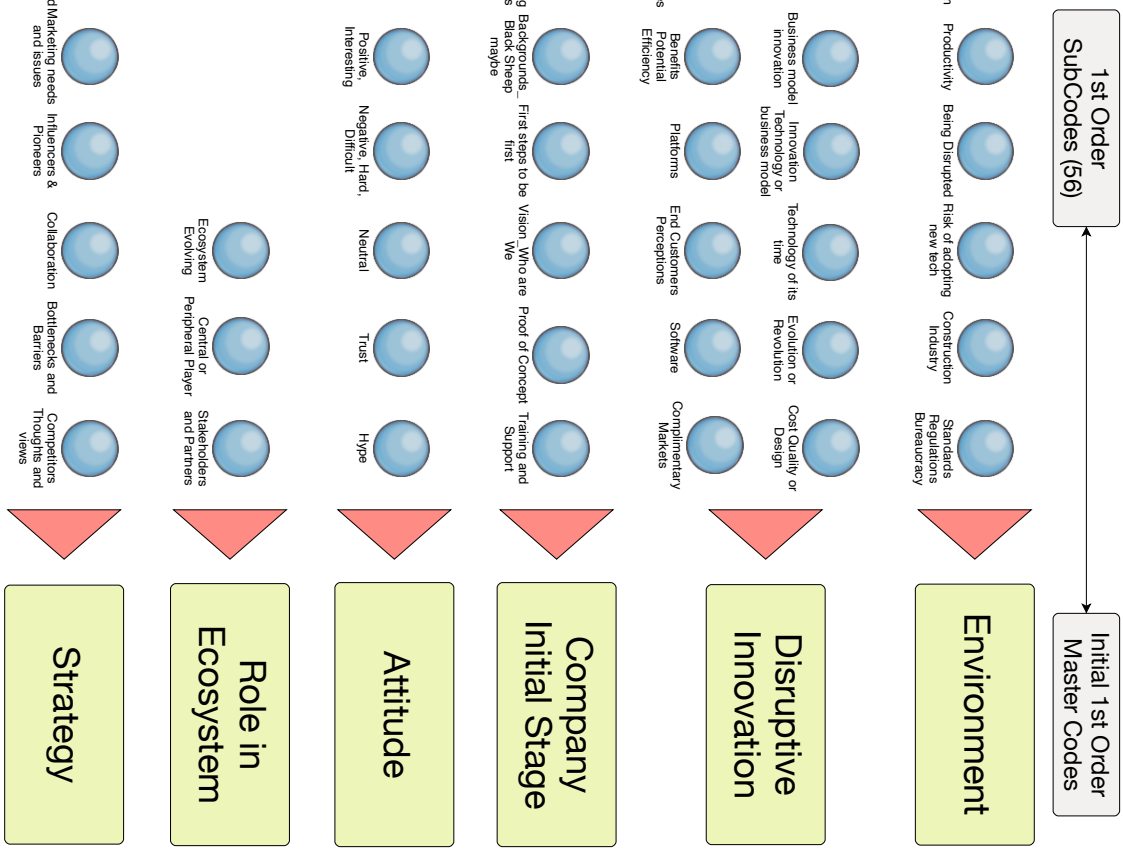


Figure 4.6 Initial Transcript Codes and 1st Order Concepts

4.10 Second Round Coding

Second Round coding is to "*develop a sense of categorical, thematic, conceptual, and/or theoretical organization from your array of first cycle codes*" (Saldaña, 2015:234).

The initial data analysis (1st round coding) extracted first order concepts from the transcripts and literature enabling me to design an initial strategy toolkit for new

ventures. The 2nd round of coding was more detailed and therefore increases the risk of my own personal biases coming through, but I hope that this two-stage approach will reduce any influence I may have had and reinforces validity. Again, referring to 4.7.2 above, I followed the most suitable code types for a novice coder. As I moved between the Transcripts and the Literature, I was able to further distill the codes from First Order Concepts into Second Order Themes. I used a combination of keyword analysis and constant comparison to identify the categories and constantly compare codes to those already coded to find patterns and keep iterating until no new codes emerged and these core themes could then form the basis for the central focus of my findings (Savin-Baden & Major, 2013).

Axial coding determines which codes in the research are the most important ones with duplicates removed and only the best codes are selected as the dataset is in effect reorganised and recombined as viewed through a different lens. Diagrams and charts of the phenomena at work are encouraged during the axial coding process, which I have used in my findings and the contribution to theory. These displays shown as matrices or flow diagrams bring the concept codes to life and helped me see where the story of the research data was pointing (Saldaña, 2015). Using the axis and timeline approach helped formulate ideas on how to combine the previous research on structure to affiliation along an axis and overlay the concept of magnitude of disruption.

4.11 Second Round Analysis

I started to build my coding structure with an initial Mind Map on NVivo. This began with a top down assessment of the Initial codes to see how they might be arranged. Projects typically do not have more than about ten hierarchies, and each hierarchical structure should not be more than two or three layers deep (Jackson & Bazeley, 2019:106).

I started with the transcripts 62 initial codes after the 1st round coding, of which 32 were considered the most relevant to construct a toolkit from. These were categorised into six major themes which encompassed the initial codes, ranging from 7 to 4 initial codes in each major theme. At this stage the themes were still only loosely defined and served as questions, such as *"How to get some momentum - Getting recognition"* (Figure 4.7 Initial 2nd Order Themes).

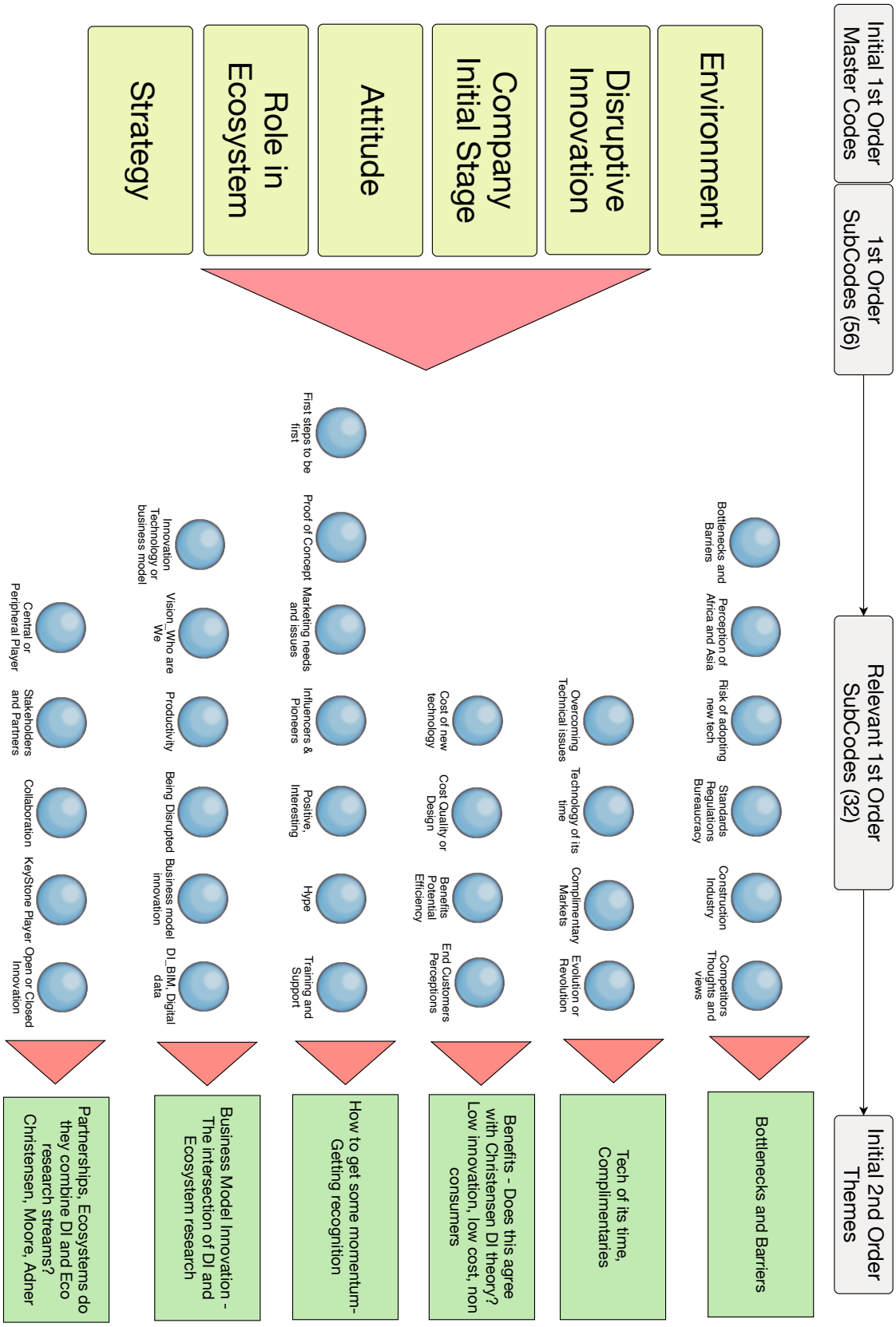


Figure 4.7 Initial 2nd Order Themes

These six Initial 2nd Order Themes were them deeply analysed against the existing research for contrast and comparison until a distinct set of the final theme titles could emerge, which are illustrated in Figure 4.9 below, that could form a toolkit.

This is where the time spent using NVivo to code 86 articles proved extremely useful. It was now easy to compare codes between the two data sets, again initially using the visualisation tools in NVivo and find commonalities and differences (See Figure 4.8 below).

Standard analytical techniques employed included the use of tabulation and graphs to highlight linkages (Miles & Huberman, 1994). The findings were constantly compared and contrasted with relevant existing literature to find any connections, inconsistencies or contradictions as part of the analysis (Eisenhardt & Graebner, 2007; Yin, 2018)

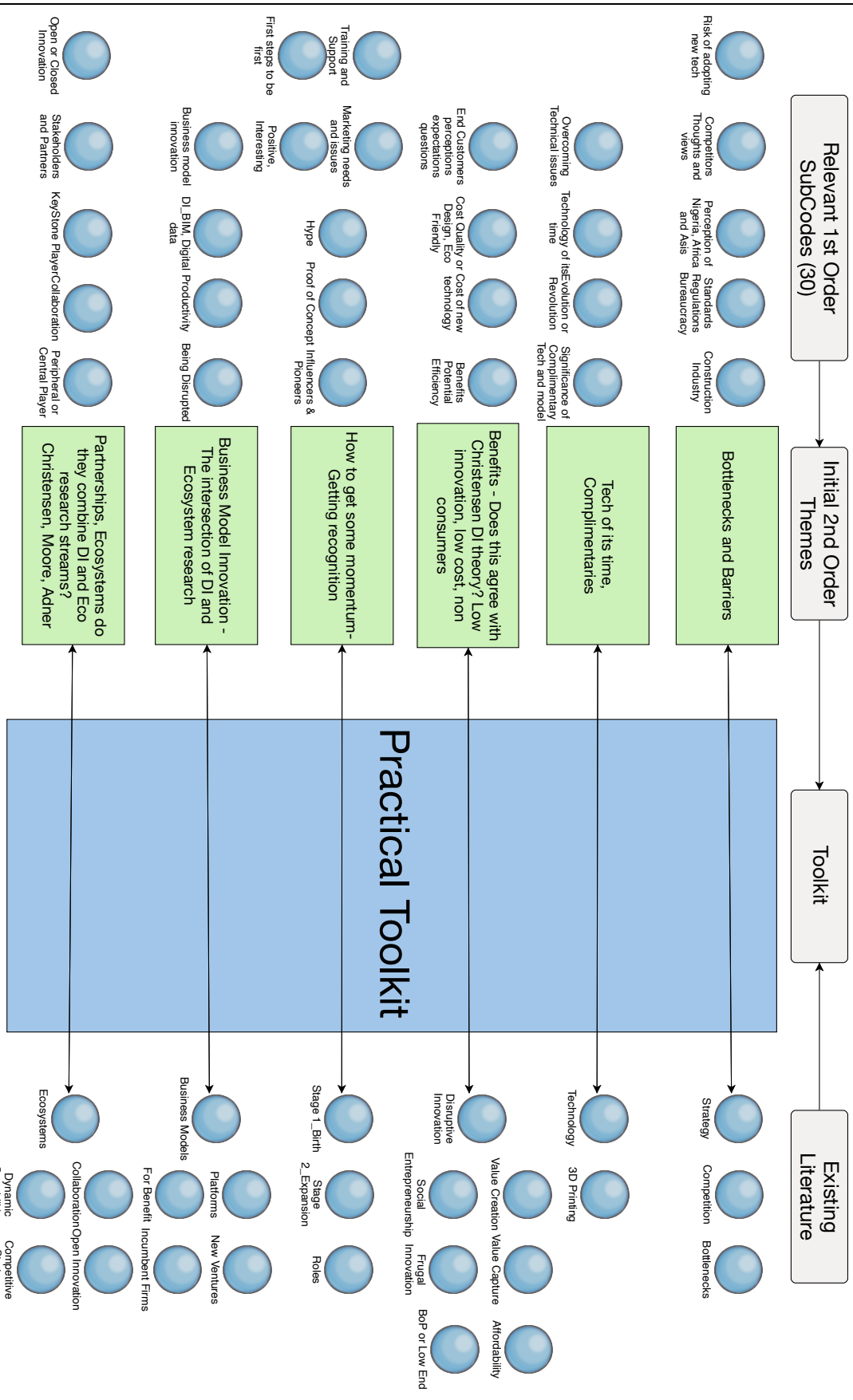


Figure 4.8 Second Order Themes Analysed using Transcript and Literature Codes

Once I had a full set of 1st Order Concepts and 2nd Order Themes, the data structure allowed me to configure the data into a graphical representation the progress from raw data to codes to themes and into a toolkit, demonstrating rigor in qualitative research (Gioia et al., 2013; Tracy, 2010). This is shown in Figure 4.9 below. These were used to frame the resultant toolkit presented in the Outcomes chapter.

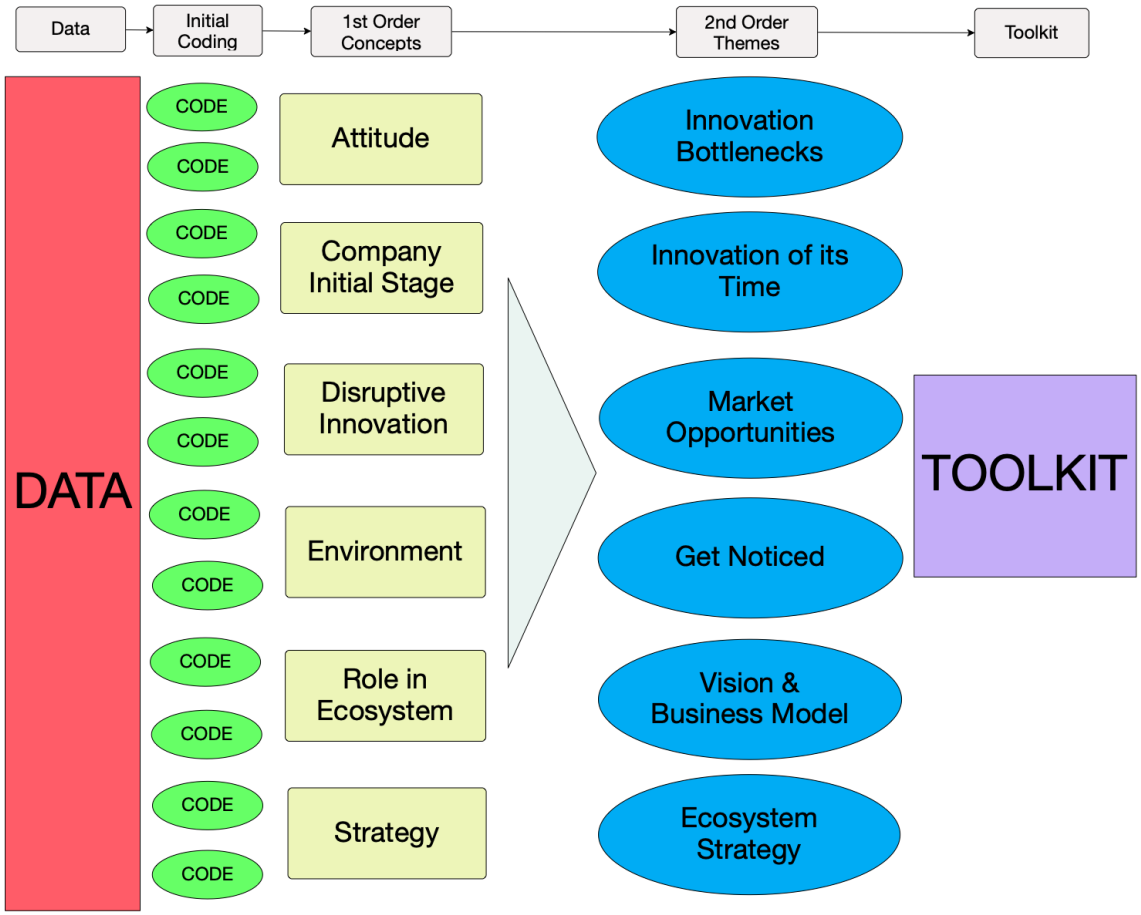


Figure 4.9 2nd Order Findings

5 Findings & Discussion

5.1 Introduction

This chapter contains the findings from the analysis of data collected during this research study. As this is a qualitative research study the results are reported and discussed at the same time, to keep a more reflexive, interpretive stance (Lee & Lings, 2008). For this multiple unit of analysis case study, the entire findings and discussion consists of generalised cross-case analysis rather than separate chapters devoted to individual case studies. And each section contains both descriptive and explanatory topics related to a specific cross-case issue or theme, with individual case data disseminated throughout each section (Yin, 2018).

As a reminder, the design of this case study was to discover themes that could lead to generalisations, in the form of the practical toolkit that (a) corroborate, modify, reject, or advance existing concepts or (b) present new concepts that arose from this research (Yin, 2018).

The qualitative data was analysed through iterative coding rounds and pattern matching into concepts and themes to uncover their meanings (Savin-Baden & Major, 2013). A detailed description has been provided and plausible rival explanations examined, as part of the findings and discussion as the strategy to identify and address rival explanations helped interpret the strength of my findings (Yin, 2018).

5.2 Summary of Key Findings

The following sections provide a rich, in-depth account of the collected thoughts of the research study participants. They highlight that the construction industry is ripe for disruption and signpost areas of interest for innovators to consider whilst also flagging up hurdles and barriers that they will encounter. The benefits of the latest technologies and processes are clear and obvious yet the apparent inertia and cynicism from incumbent participants underscores the challenges this industry faces.

The six major themes that emerged from the multiple rounds of coding are: *Innovation Bottlenecks, Innovation of its Time, Market Opportunities, Get Noticed, Vision & Business Model* and *Ecosystem Strategy* with sub themes as shown in Figure 5.1 below.

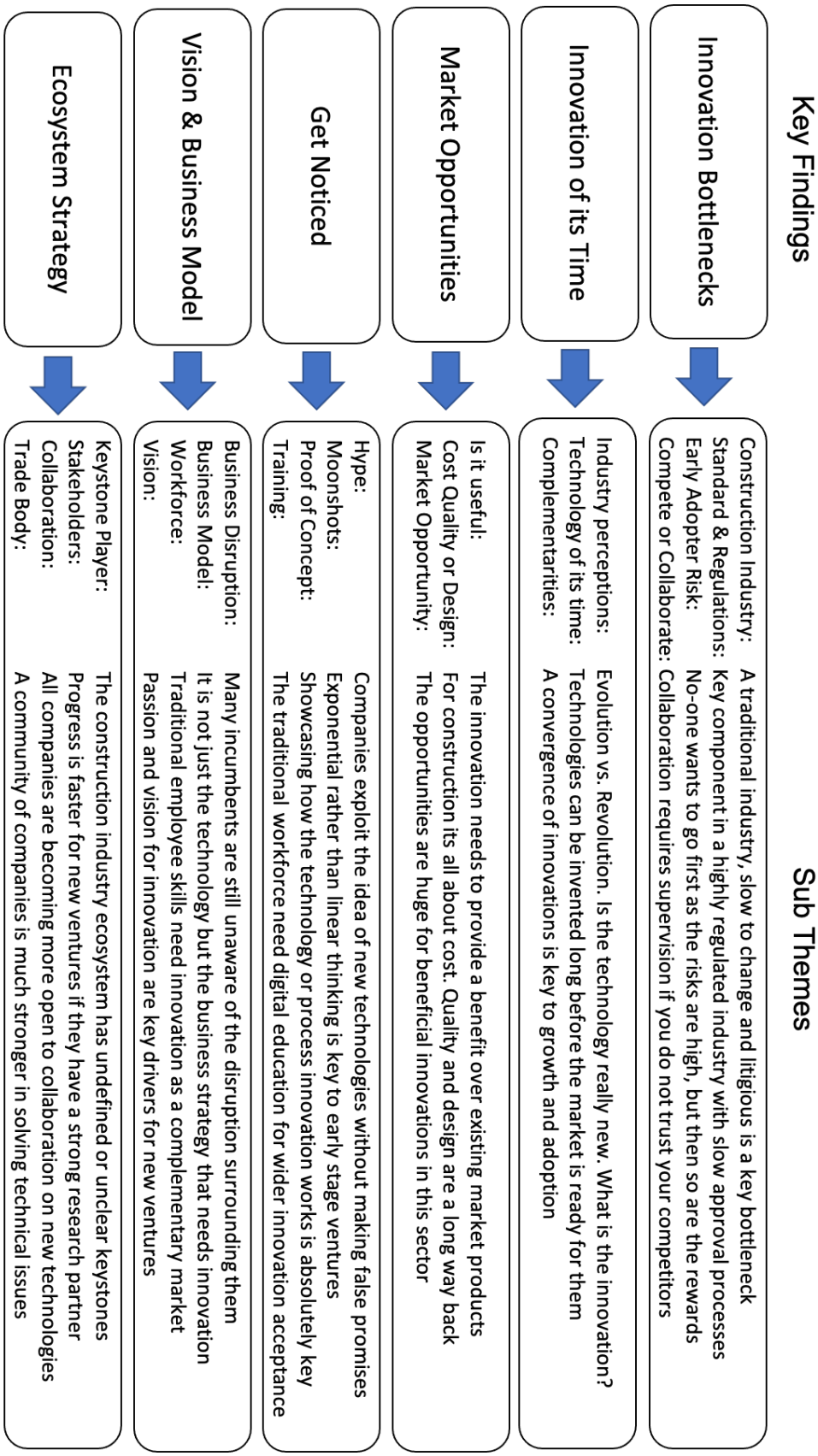


Figure 5.1 Summary of Key Findings

5.3 Innovation Bottlenecks

5.3.1 Construction Industry

The construction industry is a 12 trillion dollar market, which is still growing. I think currently 3D concrete is, let's say, 10 million dollars…So before it's really getting mainstream. It's just enormous. The construction industry is so enormous. A lot of niche markets. *I015_3DBeta*

Previous research highlights how incumbents in a particular industry have the advantage of already understanding the playing field they currently occupy. They have utilised existing barriers to deter entrants and establish a perceived unsurmountable advantage (Porter, 1985). When considering the construction industry, it is apparent that almost all interviewees had a universal image of the industry and its qualities. Every participant viewed the industry as *"a tough crowd. I think they'll get there, but…it's a very slow-moving industry…It's a very conservative industry (I017_3DAlpha).* The sheer size of the sector was seen as both an impediment and an opportunity for disruptors to enter this area, as although *'building a house in an African village is one thing, building the Gherkin in Central London another"* (*I010_SoftAlpha)*, so initially innovators must only target certain sectors. Therefore, before a new venture can build a successful enterprise and the necessary ecosystem to compete, they need to research the area they wish to compete in. Especially in such a traditional industry viewed as *'dinosaur-like' (I013_UniAlpha)* when it comes to innovation.

I think the whole industry isn't innovative enough. In fact, the construction sector, having worked in a few sectors, this is absolutely the least innovative of any sector *I047_DoorsAlpha*

This is in part due to the perceived barriers to regulation for the large scale projects; regulation, capital, land availability, resource requirements which can be used as bottlenecks to restrict access to create and capture value. It also alludes to an industry that is still engaged in traditional business models and mindsets with several participants commenting that residential house building has not really changed for hundreds of years. A 18th century townhouse in London was constructed in a similar method to today's brick and mortar houses, whilst a 16th century Tudor manor house uses a similar timber frame as today's bespoke designs. The process of housebuilding still uses a standard process, described in the stages set out by the RIBA Plan of Work 2020 (RIBA, 2020), which a Victorian engineer would be familiar with although it has been updated in 2013 to incorporate BIM in its first major overhaul in 56 years. In

ecosystem terms, the construction industry can encompass, currently, small players in certain focused fields such as 3DCP whilst also being part of a much broader ecosystem where key players may be governments commissioning large infrastructure projects. My analysis on this is to view an industry as a series of *nested* ecosystems through which innovation can either be localised or industry wide. This relates back to the original idea of an ecosystem by Tansley (1935) as a complex network or in my view a series of complex networks. To use the example of the house building process as a subset of the construction industry, it can be described as a hybrid network of smaller ecosystems. Currently it is mainly still a paper based process, even though the initial designs will be completed by architects on a CAD software program such as AutoCAD, these 3D computer designs are often then printed out as 2D paper drawing to be used by the construction teams on site along a standardised but inefficient flow process.

Each stage of this process incorporates a smaller ecosystem of players with a specific value proposition or focus. For example, the first stage of the construction phase, is usually ground clearance and foundations, which will include a different set of players and value proposition than the tradesmen used on the first and second fix at later stages of construction. In the UK, the self-builder market is only a small proportion of the total houses built so client input is usually limited or non-existent for larger housebuilding developments. It is certainly not a customer led activity. See Figure 5.2.

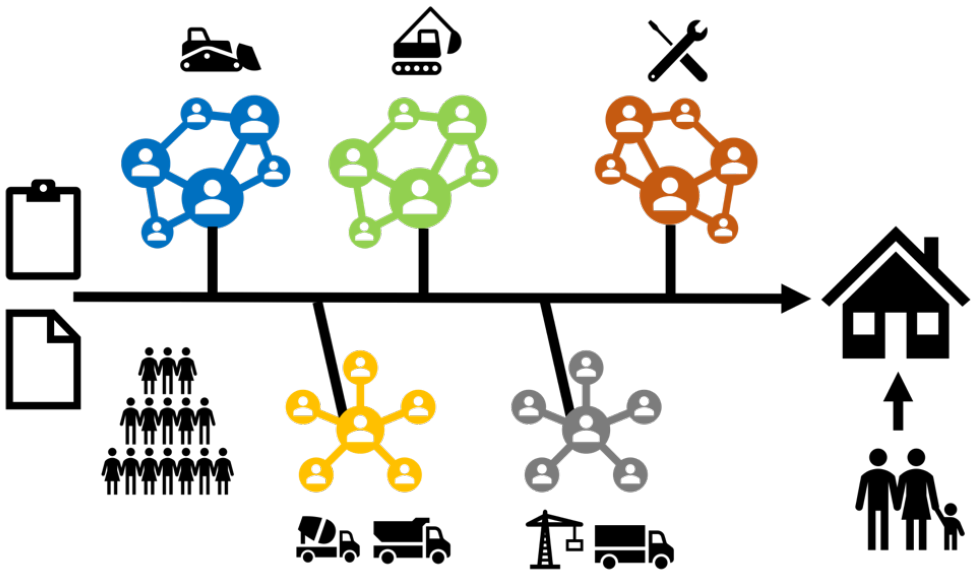


Figure 5.2 Current Housebuilding Process

The 3DCP companies all understand the need for a focused approach to be successful. As such before venturing out with their technology, the 3DCP companies

have conducted several years of market research and analysis within direct or indirectly connected fields and identified where they see the initial starting point for their innovation. This has generally been with the 3D printing of the walls and sometimes the groundworks. This only represents approximately 20% of the total process and cost of a typical house. As the pioneer firm does not have the luxury of entering an existing ecosystem (Overholm, 2015) they can utilise some of the previous work seen in existing areas of that industry. So, it follows that 3DCP players can follow the roadmaps in adjacent ecosystems already seen at work in the construction industry or other sectors.

Whilst at this early stage of innovation in the process, that does not mean they are not already looking at the future prospects and determining a path to reach higher level of ecosystem layer.

We are confident that in three years we can maybe, if everything goes well, we can address 50% of the total house with the technology we have developed. Then we can start to talk about prices being reduced into something that makes a lot of sense.

I017_3DAlpha

In effect the 3DCP companies are employing a bottom up organic growth approach to overcome barriers, following the disruptive innovation model to create and capture value (Christensen & Raynor, 2003).

For BIM it is being led by governments to force construction companies to adopt new processes. They have identified a global productivity problem and are now acting as a keystone player (Iansiti & Levien, 2004a) to guide the industry towards adopting innovation. In effect it is a top down approach to breaking existing bottlenecks and barriers. They are looking at utilising known successful practices, which are not currently being used in construction but in other sectors such as automotive and industrial manufacturing. This still presents both challenges and opportunities as incumbent firms collaborate or compete to survive in the new environment.

You look at BIM…We're in that process right now of understanding what it is. Where it's used. What the benefits are. And the challenges. And how we need to respond to that.

I002_SoftAlpha

Regardless of whether a top down or bottom up strategy is employed, both are focused on building a value proposition around disrupting the existing status quo and enabling new entrants into the existing ecosystem (Adner, 2006; Adner, 2017; Jacobides *et al.*,

2018). It is how to envision the baby steps to overcome the construction industry's current bottlenecks and barriers that leads to a deliberate ecosystem strategy to develop the ecosystem required. The first of these is a rigorous approach to the certification and testing of the product.

5.3.2 Standards and Regulations

Process approval or certification or whatever, is critical. The first step. Once you've done that, okay you're in. But until you've done that, it's nowhere.

I012_3DPAM

The companies involved in both 3DCP and the wider BIM ecosystem all recognise that a unified set of standards and regulations is a key requirement if a new technology or process is to be adopted by the industry. With BIM it is governments that have mandated that industry participants follow their guidelines even if, as seen with BIM Level 3, these may not have been specifically written yet, a direction of travel has been initiated. As construction moves towards a digital future these standards are an important component and combine elements of interoperability and technology development (Teece, 2018b). But for 3DCP, it is at the smaller community or sector level that is already discussing how this can be achieved. Building on the above idea that a new innovation should, using an academic analogy, stand on the shoulders of giants, the views of the timber frame construction companies, who tried to disrupt the industry in the 1980's act as an antecedent. All of them agreed that a certification or regulatory standard was paramount in order to focus the industry around a minimum level guideline or benchmark.

The CE mark transformed things because it unified the standards for a product, which is pretty important. *I018_WoodBeta*

This may have been due to the problems the industry had when timber frame tried to disrupt the traditional masonry house building sector. Without a minimum set of requirements or certification of competence, several high profile incidents involving fires and building collapses, quickly led to a public mistrust of the technology which has taken the past 30 years to recover from. On review it was found that rogue companies without the skillset had entered the market and their shoddy practices had caused bricks to fall off the frames, whilst the fires were all a result of arson attacks before the timber frames had been treated to give fire retardancy. This however came too late to

rescue the market for a generation in England. What was interesting is that in other countries such as Germany, US and even closer to home in Scotland, this negative reaction was not seen. Perhaps due to the abundance of timber from local forests in these locations gave a better economic incentive to overcome issues and therefore more effort was made to address any misconceptions early.

By publishing standards, detailing that gets more people comfortable with it and it becomes more embedded, because (it's) the set of rules that people can follow.

I014_WoodAlpha

For such a slow moving industry, heavy with health and safety regulations and building codes, the new ventures in 3DCP and BIM need to ensure they do not make a similar mistake. All those interviewed were highly aware of the need to test their technology. What was interesting was that some of the prototype buildings so far demonstrated added structurally unnecessary components to their design in order to meet existing building regulations. As an example, several buildings were made to add steel rebar rods within an existing pre-approved concrete to hold up the roof, even though the 3D printed walls strength was calculated to be nearly 3 times that typically required. This was due to the building standards officer being unable to deviate from existing rules as the product was too new and had yet to be approved. This came up repeatedly as a potential bottleneck to mass adoption of the technology, which may delay its uptake or limit its use for the next couple of years.

To get a new material approved to use in construction takes about 10 to 12 years. And so, you've got a battle. If you want to bring something new, like 3D printing for example. *I010_SoftAlpha*

Again, end user interviewees cited an example in Africa where a new type of concrete building was erected in the 1990's and which has subsequently proved to be a very high maintenance project. Whilst concrete may be a known product, the material being extruded through a 3D printer requires some modifications and the effects of these may take time to be tested and approved. Finally, the industry, which has a poor safety record compared to many other industries, has led the companies to focus their attention on getting the printers certified for use on a building site. This is regardless of the fact that with 3DCP, the operators can stand away from the machine during operation at a far greater distance than many other manufacturing machines and thereby operate much more safely than existing machinery.

We have set our standards test that we wanted, for now, all of our printers to be EU certified at least…Because then, we know we can go to the Middle East with EU certified, CE certified material, and they will accept it, and we can go to the US…

I017_3DAlpha

But once a product has been prototyped, demonstrated and tested, new ventures will then face a second innovation bottleneck.

5.3.3 Early Adopter Risk

Some of the risks there are with new projects, they just didn't want any part of it. So, I think that's the same for many of the big companies. They don't want to take the risk.

I017_3DAlpha

Adner (2012) discusses the need for companies to recognise the types of risk in their innovation ecosystems; execution risk (how to develop your innovation to give a market benefit), co-innovation (aligning with other innovations to transform your innovation into a successful market product) and adoption chain risk (the need for other to adopt the innovation before end users can see the full benefits). Adner (2012) believes that ecosystem leaders capture outsized gains after the ecosystem is up and running, but in the beginning, they have to build and invest for everyone's benefit with all the risks that entails, whilst followers take on smaller risks. Leaders get to set the industry rules and get the publicity and brand recognition which can last for years but the risks of failure are also large. For such a conservative industry the risk of adopting and promoting a new technology has its difficulties. Large well established firms do not want to be associated with failures. For the 3DCP technology, the first concept houses were constructed under the umbrella of a research project, to allow existing companies to be able to distance themselves in case of issues

Whilst there is a financial cost associated with a failed project, it appears that it was more operational and reputational risks that made these firms distance themselves. One large construction company even went so far as to say they were happy to be involved and provide resources as long as their name was not mentioned on any of the publicity and marketing pictures, just in case the house collapsed, or someone was hurt (*I017_3DAlpha*). It is not just the 3DCP companies that experienced this. The BIM software developers also found clients unwilling to commit at an early stage. Firms were more likely to use small pilot projects to get comfortable with how this would

affect them. Akin to when Microsoft or Apple release new versions of their operating systems, established firms wait to see if any issues emerge before switching across.

We certainly haven't moved first. Where we're doing…is in partnership with a sponsor, a customer. It's quite a risky strategy to do that, you've got to be very confident that you haven't got it wrong. *I002_SoftAlpha*

This supports the first mover matrix proposed by Adner and Kapoor (2010) for determining whether it is better to be a first or second mover depending on the level of execution and co-innovation challenges. This raises the idea of smart timing (Adner, 2012) to look at the whole innovation ecosystem challenges and not just the readiness of your technology as a standalone component. The disruptor still needs a set of complementary markets.

The second mover normally becomes the most successful rather than the first mover… What the first mover very often lacks. First mover tends to be, particularly in our industry, high with technical people that have never sold or marketed anything

I010_SoftAlpha

It is therefore a question of internal company and ecosystem resources on how to advance the innovation. Without the internal dynamic capabilities (Teece, 2007) required to go this alone, the SMEs cannot afford to develop a product on their own without the support of collaborators as the risks are too high both in capital, skillset and marketing, confirming the resource dependency for new ventures (Pfeffer & Salancik, 1978). But an indirect issue is the skillsets of the users who will be expected to operate the software or machinery once it has been developed. Several mentioned that the construction industry has not traditionally attracted the highest quality candidates and building sites are still populated with lower skilled labourers;

The sector is not really the first choice of your graduates, your MBA guys.

I047_DoorsAlpha.

You'll have an IT CIO of an organisation come in from outside of construction and go, "What have you got here? You're kind of archaic." (laughs) *I004_SoftAlpha*

This is especially true in some developing countries, where several of the interviewees saw it as a potential issue to introducing a new technology and a key complementary market requirement.

It's been an issue where you have some new technology, … you don't find the skilled labour for it or the personnel. *I027_DevAlpha*

The smaller companies and software providers are all conscious of the need to target specific markets where they can create value, both for the ecosystem and for their company to reduce the early adopter or first mover risks. Many were cognisant of the risks to be first adopter as opposed to waiting for the technology and complementarities to develop (Adner & Kapoor, 2010; Teece, 1986). The barrier to entry may be low to develop the technology but unless the companies have the whole ecosystem strategy vision then they still may not capture the value.

The guy who bought the dental technology off us ... They bought all of our know-how for a not too princely sum. And his comment was, "It's the second mouse that gets the cheese." *I012_3DPAM*

This is a reference to the old adage that it is usually the first mouse that gets caught in the trap and the second one that gets to eat the cheese. Although this contradicts the best-selling book, "*Who Moved my Cheese?"* (Johnson, 1998) where it is the mouse that explores who is more likely to find the bigger cheese store, other interviewees agreed;

If you go first and do it well, I guess your chances of failure are higher but if you do well you've reaped the benefit from being first in. But there's a lot to be said for fast followers isn't there because you can just tweak it to not make the same mistake *I043_UniAlpha.*

So being an early adopter has inherent risks for bringing innovation into the construction industry regardless of the vision and enthusiasm that the disruptors have for their product. The innovators need to be careful to choose the correct partners and have a high degree of trust in them. Trust was mentioned by many of the interviewees as a major component to choosing who they were willing to share their technology with;

Nothing works without trust, it's a trust of integrity, and a trust of judgment.

I001_SoftAlpha

This brings into focus the ecosystem balance between cooperation and competition (Brandenburger & Nalebuff, 1996; Hannah & Eisenhardt, 2017) in order to spread some of the first mover risks across a community of players rather than an individual firm.

5.3.4 Compete or Collaborate

A lot of our competitors are companies that are also aiming to start printing concrete…They are competitors, but I've got them on speed-dial…We know what the other people are doing. It's a pretty small community. *I015_3DBeta*

Adner and Kapoor (2010) describe how the position of bottlenecks, either upstream or downstream of the focal firm, affect the firm's ability to create value as the ecosystem challenges are unevenly distributed across ecosystem roles. This can either enhance or erode a firm's ability to create value for itself depending on its understanding of the surrounding ecosystem and their role within it. Component technical challenges can propel a focal firm whereas complement challenges can act as a drag. So, disruptors and innovators need to consider whether any upstream challenges limit the innovation getting to market, or if downstream challenges restrict its full potential. These firms have to make a decision on whether to compete or collaborate with others in the same sector. Firms that compete too much hinder an ecosystem from developing (Ozcan & Santos, 2015), yet firms are wary of collaborating too much in case they give away too much of their intellectual property and innovative advantage. Yet an ecosystem cannot create value for a firm until all the ecosystem component parts and complementarities are in place (Jacobides *et al.*, 2018) so there is a balancing act to be made between this competition and collaboration. When firms compete the most value is captured if a firm can restrict competition in their own component part whilst encouraging competition amongst the other complementary components (Santos & Eisenhardt, 2009). When they cooperate then the value is created for all players, if one or more pioneers emerge to direct the activity on the required component parts (Ozcan & Eisenhardt, 2009). For nascent ecosystems in the early stages of a new industry such as 3DCP, navigating this balance can be challenging. Hannah and Eisenhardt (2017) present three strategies (bottleneck, component and system) for how nascent ecosystems develop and highlights the different strategies for firms to create and capture value from their innovation over time. Whilst the interviewees acknowledge

they are competing, they are also aware of the need for cooperation due to resource constraints (bottlenecks), especially capital and scale.

I would say there's still, obviously there's competition, but it's also a very small market. So, we are so few and everybody knows each other. And so, we share a lot. I think in between, obviously not our most valuable secrets. *I017_3DAlpha*

Unlike the observations on solar service providers (Overholm, 2015) where the companies did not have much interaction between themselves, many of the 3DCP companies currently see themselves in a tight knit community and share information. They understand that at this early stage it is more useful to collaborate rather than compete (Kapoor & Lee, 2013; Moore, 1993). This was mainly led by pioneers, which I define as firms that had been active in this industry for over 2 years and who had already built, or are in the process of building, a proof of concept house. Led by these pioneers and far sighted participants, this community has instigated conferences and lectures for the past 5 years to exchange information and to act as a sounding board to promote the technology. By looking at innovation ecosystems as complex adaptive systems with four stages of integration; networking, coordinated network, cooperation, collaboration (Russell & Smorodinskaya, 2018) it appears that the pioneer 3DCP ventures are more open to exchanging data at the top level of collaboration than other sectors at this stage of the technologies development. I see this more as a knowledge ecosystem by definition and therefore consider this type of ecosystem as congruent to the concept adoption or birth stage of an ecosystem. Players in this community realise they are better collaborating than competing to develop an innovation.
Compare this with the experience of 3DPAM when 3D technology was in its infancy 30 years ago, and he struggled to form any collaborative bond with other pioneers. In his opinion this led to a much harder time marketing and advertising the technology, limiting its growth potential in the early stages.

I felt my number one competitor basically swallowed The Art of War book. There was a lot of misinformation went on. And he took being a competitor very, very seriously.
I012_3DPAM

For the two innovations studied, the results suggest different approaches occur even at the different stages of ecosystem growth. For the 3DCP companies in the concept adoption phase (D'Aveni, 2018), the majority of them want to pursue a whole system approach with 3DBeta, 3DRho and 3DZeta all looking to provide a one stop shop for

the whole system from design through to completion. Others like 3D Alpha were initially focused on a single component, the printer, to begin with but have now embarked on projects to overcome technical issues they have encountered. Whilst their objective is to be a technology company rather than a construction company, they still have to construct buildings with their partners to showcase their innovation. So far none has followed a bottleneck strategy which proved the most successful for the solar panel companies (Hannah & Eisenhardt, 2017). This may be because of the early stage of the technology, the enormous size of the industry and so far, no clear keystone players or leaders emerging. To move from their current birth or concept stage all these companies need to recognise the key bottlenecks that currently exist and how they will address them. So far, the majority of efforts observable is to showcase prototypes and build pilot developments using the large capital available from governments such as Dubai and Saudi Arabia, rather than an individual customer financing model. So far, I see no strategy for a wider ecosystem strategy for how customers pay for these houses and how mortgage providers will be happy to lend for 30 years against this type of property. Based on the previous solar industry research the new ventures should consider a bottleneck strategy to combine competition and collaboration to pursue mutually beneficial interests whilst also capturing value along the way.

For BIM, the top down approach has meant that specific institutions and bodies have been formed to promote the technology and diffuse information across the sector with government publications such as Construction 2025 and the TIP programmes (BIS, 2013; IPA, 2017) as well as trade backed sites such as BIM+ (www.bimplus.co.uk). For BIM (digital twins) it is more how it will get implemented across all companies, rather than a specific innovation in a company.

Digital twins, we bring several disciplines together, we have disparate models, we've got architects, we've got architectural model, we've got structural engineers, we've got structural model, mechanical, electrical plumbing, services that actually make the building tick, and these all come together. *I048_SoftBeta*

It is policy and process innovation led by government and consultants rather than individual disruptors. Ansari and Krop (2012) constructed a framework on how incumbents can survive a radical innovation and fend off disruption. Part of their framework finds that the less evolved the complementary market the higher the incumbent survival. They also find regulation favours an incumbent in the short term but hinders their flexibility. Therefore, for the construction industry, with its high

regulation and so far, lack of a complementary marketplace, disruptors are going to find incumbents harder to displace. Their ecosystem strategy for BIM may find that it is better to envision this traditional industry will be disrupted more by whole system innovation than a single technology at this point.

BIM is not a technology, BIM's a theory, it's a methodology if you like.

I010_SoftAlpha

The BIM disruptors need to gain the support of other incumbents and need to continually adjust the ecosystem strategy as the innovation moves through the different levels of adoption. If not disruptors likely face incumbent's retaliation and therefore may suffer high failure rates (Ansari et al., 2016). They need to remember that disruption is a process (Christensen & Raynor, 2003) and try to offset market power of incumbents by reframing the disruption (Santos & Eisenhardt, 2009) as a whole system benefit. The software companies appear to understand this as they are tentative about moving into existing clients perceived areas of expertise and are looking to work collaboratively on pilot projects rather than announce themselves as a platform provider that displaces the incumbents

So, we're quite an attractive partner for…people who are offering …complementary services that would be very attractive. Clearly, if they're offering things that overlap, then we start to say, "Hmm. Not so sure about that." Because you might threaten what we do, because it's a means of intruding or getting in there. You know, they're like, "We don't touch your bits." Then there's the inclination to say, "Oh, well, we could just expand what we do and push out SoftAlpha." *I004_SoftAlpha*

5.4 Innovation of its Time

5.4.1 Industry Perceptions of Innovation: Evolution versus Revolution

Many people think that 3D printing is completely new in the construction industry, but this is a video from San Francisco from the late 30's. He is actually doing very close to what we're doing right now. It's not automated, it's not computerised, but he's actually building layer upon layer of concrete. *I017_3DAlpha*

Figure 5.3 Additive Construction, 1930's San Francisco

One of the most surprising findings for me was that whilst almost every interviewee believed in the technology to make a difference, many saw it purely as an evolutionary process rather than a revolutionary one;

This technology is not new. It's, in fact, more than 30 years old. *I049_3DAlpha*

I've been in additive manufacturing for 30 years. Most of you may only become aware of it in the last few years, but actually, yes, it has been around for a long time.
I012_3DPAM

Even amongst the innovative companies in both 3DCP and BIM, whilst all of them believed in what they were doing to improve the industry, a majority still saw it as a progression rather than truly disruptive with the exception of a few or the 3DCP pioneers. This doesn't really gel with Schumpeter (1934) *creative destruction* theory or maybe it does in that whilst people see and believe that disruption is coming, they seem detached from how it may radically change their industry. Especially for the construction sector which seems to drag incumbents down into believing that it is such an enormous industry that change will only come slowly and they will have the time and chance to see threats and see them off. Maybe it is a mindset that innovation has been beaten out of them through repeated failed attempts to see innovations come through.

Look what we did in the last 10 years for housing and nothing has changed has it?
I022_ConstructAlpha

Even BIM has been around it for 20 years, so it's nothing new *I017_3DAlpha*

Or perhaps it is that incumbents are already attuned to the reinvention process in life and see disruption as evolutionary rather than revolutionary events. In the timber frame precedent, the attempt to drastically increase house building through their technology could not quickly overtake the traditional brick and block sector. Even though the advances in 3D printing technology and the rapid speed of new material development, incumbents saw that getting acceptance takes a long time.

Concrete started with the Romans originally 2000 years ago…No I think the only revolutionary part is the machine can do the concrete 3D printing, whereas timber frame it's not revolutionary is it? *I044_ConstructBeta*

We've been making timber-framed buildings for a very long time. The Vikings made timber-framed buildings. This is an old technology. *I019_WoodGamma*

Timber and concrete have been used to construct homes since the Vikings and Romans so in the minds of most, it is not the materials that show any innovation or disruption. For the 3D construction printing, it is only the automation of the process that is new. As shown by Figure 5.3, the idea of continuous layer by layer construction of homes was prototyped in the 1930's. The only difference is the use of an automated robotic arm that has been introduced now. And the printer technology is based on the same computer code and techniques that have been developed for plastics and metals, which have been around since the 1980's. Yet Gartner identified 3D printing as "*a rare example of a single technology that has become truly disruptive by itself*" (Prentice, 2014). So, the question is, if it is not the materials and it is not the CAD/CAM technology, what is the innovation and why is it happening now?
And for BIM, why do the software developers believe that it has been around for 15-20 years yet only now it is being implemented widely.

There's nothing in BIM that people haven't been advising people to do for 50 years in the construction industry. The technology that underpins BIM has been there again for the last 15 years, which is computer aided design. *I010_SoftAlpha*

Coming back to how disruptive innovations take hold, this is the low end innovations moving higher up the chain to start impacting incumbents (Christensen *et al.*, 2018). Perhaps it is also the ecosystems being formed as either structure of affiliations (Adner, 2017), that has taken time to be established. After all in the construction industry, the use of platforms and manufacturing giants (D'Aveni, 2018) has yet to be seen in 3D and BIM, although some are now developing their strategies. Perhaps it is the timely collection of complementary assets and technologies that is emerging now (Adner & Kapoor, 2010).

5.4.2 Technology of its Time

All the technologies are there, it's just bringing the technologies together and so we can create something. *I045_ConstructBeta*

Adner and Kapoor (2016b) in *'Right Tech, Wrong Time'* bring up the issue of when a new technology will supplant an existing one. If all the technologies have been around for up to 30 years, the main question has to be why these processes and new technologies have not until now entered the construction sector. It does suggest as many of the interviewees stated, that it takes a combination of technologies to emerge and complement each other before serious progress is made. This confirms the findings of Adner (2012) that single technologies whilst impressive in their own way, will not make it to mass adoption until the complementary assets and technologies, be they skill sets, processes or other technologies are available. Just as Apple was not the first to invent the MP3 digital music player, so the initial inventors and innovators may not be successful in launching their product without an ecosystem behind them. Behrokh Khoshnevis, a professor at USC was the first to write articles about 3DCP in 2003. Yet although he has written many articles since and set up his own company, Contour Crafting, he has yet to build a proof of concept house. This maybe because he was more interested in developing the technology from an academic point of view rather than commercialising it, or it may be because whilst his skills are in inventing and innovating the technology, he has not built up a strong ecosystem around him to provide complementary assets for a successful launch. This raises the concept of enabling technologies (Christensen *et al.*, 2019; Teece, 2018b) that can propel an innovation towards value capture with large spill over effects as long as the complementary components and business model are also developed to commercialise it. It is this ecosystem strategy that determines the success of a technology and its gestation time.

Since those first articles by Khoshnevis in 2003, it was not until 2016 that a proof of concept house was built:

It's the same with any new technology. Like the acorn or whatever. It just does nothing for a very long time, and then several things come together at once in terms of capability of the technology, awareness of the need and so on I012_3DPAM

This also appears to be true for process innovation as well as technology innovation. Software, for automation of machines and automation of office tasks, now has the ability to disrupt existing processes. They provide a data storage system that allows instant access across the globe using cloud computing. They can eliminate labour intensive manual tasks to provide instant 3D renderings and plans of buildings. They provide instant access to supply levels and delivery status or they can utilise augmented reality to overlay 3D designs on real life buildings. This software is only just emerging across the construction sector and 3D platforms:

We're seeing the beginnings of that happening now, where software is beginning to demystify, the software is beginning to kind of de-art the process. I012_3DPAM

For BIM, the software has the ability to *"create value by compressing time" (I001_SoftAlpha)* but end users have to see the benefit of using the technology. With 3DCP this will be through pilot projects that showcase the technology and its advantages compared to existing methods. For BIM, the process may be more difficult, even though it's been mandated by governments, as large projects must take the time to understand how to use the software and its benefits. There is a balance to be found:

The balance is, is not being too early, not being too late…BIM's a great example of this. We'll say, what is it you're doing with BIM, what are the plans, etc. Where's the value going to be. How do you want to do it? How can we help. I002_SoftAlpha

The real change will come through a period of reflection and education when the existing incumbents start to recognise the benefits and start to imagine what the future for them may be. This does not make them innovators, as their chief concern seems to be cost efficiencies, but it will give them a direction of travel for the industry. Many of the incumbents when asked to reflect on the sectors they were in, started to open up about the possibilities although many soon moved back to a wary cynicism of how soon it would happen in their area.

Imagine where we're gonna be in another kind of ten years; mind blowing…you 3D print…you scan the area, you do the design on your computer, you do how he wants it to be with this thing…Slip on your augmented goggles and say this is what it's gonna look like. Okay, you're happy with that? You have a look around. Yeah. Okay. Print.

I045_ConstructBeta

I think that yeah, we're gonna start looking as an industry, different ways of building things. And that's where the modularisation and offsite manufacturers does that come into play. So, I think we'll see a lot more of it. *I022_ConstructAlpha*

When asked of the different technologies that they saw coming into the house building industry, currently the buzzwords were about offsite manufacturing plants and modular houses rather than 3DCP. Perhaps the 3DCP technology is currently too new and too small on the radar to be making an impact. With only approximately 20 houses so far built, the process needs to be refined before it hits mainstream. But what is apparent is that most of the new technologies, including modular, have not seen a large take up as of yet. One of the problems maybe the lack of a business model that can capture value from these enabling technologies rather than discrete model innovation (Teece, 2018b). Trying to capture value as an innovator is difficult if he has to rely on partners to help commercialise the technology as the rewards need to be shared across the ecosystem (Teece, 1986). The large UK house builders already have a well-established ecosystem but are mainly driven by price. The smaller housebuilders see the traditional building methods as preferred by buyers as there was a definite view that people wanted their house to be similar to those they already know, i.e. most want to live in a house similar to the ones their parents had. This was also true for the African ecosystem players. The mortgage providers wanted a house that would last at least the length of the mortgage but were also concerned on resale appeal in case of a default and hand back. The government and developers wanted cost efficient houses in large numbers but when asked how the houses should look, still referred back to traditional designs rather than some of the funkier demo houses.

So how many people copied the show home with all their interiors? …70%

I022_ConstructAlpha

It confirms the findings of Adner and Kapoor (2016b) that existing technologies are dragged out for one last shot by incumbents to serve existing customers whilst disruptors find they need more time to build the whole ecosystem in order to compete in an extension of the traditional technology S curve theory (see section 4.2.4.1 for further details). It is only when all the technologies, processes and business model come together that a technology is of its time. For the move to a digital economy, innovators need to manage their ecosystem strategy to align complementary assets, dynamic capabilities and business model (Teece, 2018b).

5.4.3 Complementarities

I mean it's interesting all the technology that is needed to do that exists today. You know, you just gotta ask the question. Why aren't they doing it? *I010_SoftAlpha*

During the early concept stage players promote their own different technologies in the hope of value creation and capture (Anderson & Tushman, 1990), but for a technology of its time, the interviewees all see there needs to be a set of complementary technologies or skillsets, that could help them further their innovation that lie outside of their firm but in the ecosystem (Adner & Kapoor, 2010). This is an important component to any ecosystem in how to bring the disruptive innovation to a mass audience (Kapoor, 2013; Teece, 1986). Whether it is through a larger partner, as with 3DAlpha, who can utilise their network of worldwide offices and marketing budgets instead of needing their own marketing and advertising division to promote the product, or whether it is utilising a worldwide platform such as Microsoft Azure on which to build the software to gain most impact from customers pre-existing dependence on Microsoft tools such as Office365, as SoftAlpha have done.

The platform effects can still be used by piggybacking on an existing software platform. This availability of complementarities can be key to a firms ecosystem strategy for capturing value from a disruptive technology (Kapoor & Furr, 2015). For the BIM software companies, building on existing platforms helps get the product to market quicker but also has less installation issues as it should work with the clients existing IT software. This helps the incumbents to build innovation quicker and cheaper and with less installation issues, than if they try to develop a closed system that other developers are excluded from and the end client cannot see synergies to existing system set up.

There's got to be a delta of common interest…So, you've now got the almost the perfect storm, in a good way, of having the technology, having the will by the suppliers, stakeholders and sponsors, but also having the buy-in of what was the weak link in the chain. *I002_SoftAlpha*

For the 3DCP companies, whilst all were focused on developing their technology, they all saw the need to incorporate external skills and capabilities. Whilst there were disparities in approach to managing the construction projects, with 3DAlpha only wanting to be involved as a method of improving their technology, others such as 3DBeta want to manage the whole process from design through to final construction.

One of the key themes that you see through many, if not all, technology introductions is you get multiple functions coming together as one. I would expect the technology to go from this rudimentary process to something very sophisticated over a number of years, bringing together a number of different things. *I017_3DAlpha*

5.5 Market Opportunities, Costs & Benefits

5.5.1 Benefits

Innovation in construction is something very valuable. We're supposed to have that to improve the life of our people *I031_GovPlan*

New innovations are pointless unless they deliver a benefit to the end user. Disruptive innovation theory is premised on the understanding that existing technology either ignores a subset of the population (the non-consumer) or over engineers a solution which takes it out of useful functionality at a reasonable cost for the majority of existing consumers (Christensen, 1997; Christensen *et al.*, 2019). Almost all the interviewees were open to the idea that 3DCP and BIM could help change the construction industry, although with differing degrees of enthusiasm and scepticism. This leads to what types of benefits can be achieved. These need to be discussed and envisioned within the innovative companies but also with the potential end users and other actors in the nested ecosystems. Again, with reference to 3D printing using other materials, and construction process management software a roadmap can be determined.

Whatever's happened with additive manufacturing is only moved forward when people have found benefits from it. And so, with the construction printing, we're looking for benefits *I012_3DPAM*

When we're innovating, we're either innovating in response to feedback or we're looking at how new technology can be used to service those…you look at BIM…We're in that process right now of understanding what it is. Where it's used. What the benefits are. And the challenges. *I002_SoftAlpha*

The case study highlights the literature's view on the benefits of the BIM and 3DCP innovations. Practitioner focused reports illustrate the ambitions of governments and industry leaders on what they expect to happen in the construction sector (WEF, 2016). Therefore, to see if these ideas are disseminating through the construction industry ecosystem, I asked follow up questions not only on the innovations they were seeing in the construction industry but also what particular benefits they were looking to achieve from them. They separated into various camps when discussing the benefits, but a very clear trend emerged when discussing cost, quality, design or other factors such as sustainability.

5.5.2 Cost, Quality or Design

What this technology is offering to the construction industry? Well, basically they say three things. They say it's faster 50 to 70%, faster completion is cheaper (by) 50 to 80%, (with) lower labour costs. And it's better because it means we can customise things, we can do intricate designs *I049_3DAlpha*

For 3DCP there was a very clear pecking order of benefits: 1.Cost, 2.Quality and 3.Design. The end users were mainly concerned with how the innovations can lower the overall costs yet still provide a good standard of housing. For the African interviewees the wicked problem of housing shortages meant that their focus was definitely on the cost point as it is imperative to provide housing as quickly as possible, especially considering their demographic projections over the next 20 years.

The key focus of innovation has to be how do we drive down costs, whilst maintaining some decent specifications in liveable home. *I032_SovFund*

More concerned about the cost rather than quality surprisingly. Cost first, then quality

I028_DevAlpha

I think cost over quality…I mean, because for most people just want one. They can deal with the quality later…Give us the shelter first *I030_MortAlpha*

And the innovators have recognised this from their interactions with ecosystem players and potential customers. Although all of them had a different plan on how to establish their business, the driving questions were remarkably similar:

Cost is the driver. We need to know that we can compete in the market, otherwise, it makes no sense *I017_3DAlpha*

It's actually not about printing…what you want is to build fast, and affordable. *I015_3DBeta*

All the questions flow from that. Like, "Well, how do you do it?" "How long does it take?" and "How much does it cost?" *I020_3DZeta*

The strategy to reduce costs was determined by the performance against existing metrics and focus on business model innovation. 3DAlpha is focused on how to reduce the cost of construction by 20% compared to a traditional build and using productivity as an extra key performance indicator. 3DZeta is looking at the whole supply chain with saving both in the construction costs, but also through its ecosystem's ability to use collective bargaining power to drive down material costs. 3DBeta is using the faster construction times as a main driver for customers. If the build time can be drastically reduced from 6-9 months down to less than 1 month, they believe being at a similar price to traditional methods of construction will still be attractive to clients.

I think in the construction process totally, we ought to be able to save both soft cost and constructions costs between 17 to 28% *I020_3DZeta*

All construction would benefit from cost efficiency by doing more offsite manufacturing and offsite fabrication…Whether it be using 3D printers or a small manufacturing plant, they would have a dramatic effect on the costs. *I010_SoftAlpha*

The incumbents also saw price as the main determinant for the main housebuilders to be interested in any new technology. For the timber frame industry, the

commoditisation and standardisation of products along with the increased use of the internet to source similar products from anywhere across the globe, had led to cost being the only driver. This has caused some of them to look to exit the business as it was a race to become more cost efficient through scaling effects rather than to quality differentiation. This tends to confirm that, within this sub sector at least, the traditional business model for economies of scale are being pursued instead of the opportunities to innovate the business model and embrace economies of scope through 3DCP and digital twins (D'Aveni, 2018). Unfortunately, this meant that they thought that the main housebuilders were building to the minimum quality standard dictated by the building regulations, resulting in large profits for the housebuilders but to the detriment of quality for house buyers (in the UK).

If you're just trying to get into the mass house building sector, it's got to be price

I018_WoodBeta

The prize for the innovators if they can get the price down to compete, will be then to increase the quality and start to erode the incumbent's position, bearing out the disruptive innovation theory (Christensen & Raynor, 2003). The move towards standardisation of parts and modular building techniques, whilst requiring large initial capital costs can "*ultimately reduce costs and create efficiencies out there" (I050_ConConsult).*

The prize for the 3DCP companies is that the printers are not so expensive, starting at approximately £100,000 for a gantry system, which is cheaper than many of the large construction equipment seen on sites today (for example, a tower crane can easily cost up to £300,000 depending on its specification) and should not therefore present a 'sticker shock' for larger companies if the perceived benefits are there. For the smaller builders, the ability to rent or lease a 3DCP printer will enable them to also make use of the technology in the near future and this business model innovation is being pursued by several of the 3DCP companies, especially 3DAlpha, as a novel way of getting a wider audience as they commercialise their technology with their strategic partner.

This ties back to how the firm's ecosystem strategy can create and capture value using the disruptive innovation. Innovators have to understand how their product can benefit the marketplace and the other players in their ecosystem to give all a common value proposition (Adner, 2017). So far 3DCP is not competitive on price and no proof of concept house has yet come in below existing costs for a comparable traditional build, but several projects with a 20% cost saving as the initial goal are scheduled for completion in 2020. This is the low end innovation starting point for disruption but

where it remains to be seen if the product is seen as initially inferior to the incumbent structures (Christensen *et al.*, 2018). The technology is capable of producing higher strength buildings with low costs for a reduced cost if these prototypes are delivered on budget.

For BIM the market benefit is in efficiency and transparency to drive down costs and improve productivity. It is not coming in at the low end as the government buildings are large scale flagship projects. Therefore it represents more of a reconfiguration of the value proposition for the ecosystem as well as disruption (Bohnsack & Pinkse, 2017). As such it is not as clear cut confirmation of Christensen's theory. Just as 3DCP is not yet cheaper or as usable for mainstream customers as existing technologies, so BIM is also expensive to implement with cost savings only seen if it is used across all projects and construction industry players

You can't sort of BIM it, part way through, you've got to be right on it at inception really.

I023_ConstructAlpha

Firms are being coerced into adopting BIM in order to take part in larger scale projects with government money and therefore take the risk that they do not win contracts in future projects so have to sink all the initial costs into the known projects they are part of. Therefore, again I see a difference in ecosystem strategy depending on who the disruptor is, top down or bottom up and the value proposition (market creating or sustaining & efficiency innovations). Incumbent firms' choices are different to new ventures (Adner & Kapoor, 2010).

5.5.3 Market Opportunity

The majority of demand right now are from middle-income to low-income countries where they're looking at building thousands of buildings. *I049_3DAlpha*

Christensen *et al.* (2019) urge the innovators to target the non-consumers in their chosen industry sector. For the construction industry when considering 3DCP and BIM, the question is who is the non-consumer and what is the market opportunity?

For 3DCP some of the companies were surprised that it was not the developed nations with a productivity issue and a declining workforce, that are currently the main enthusiasts for their innovation:

Initially, we thought that we would get all of the attention and all of the interest will be coming from the high cost countries…but likewise, a massive interest from places like Malaysia, India, Philippines, and so on. And the reason there is completion time

I049_3DAlpha

But actually, it was the middle to low income countries experiencing the huge growth in their populations that were most interested. This is due to the high numbers of houses that must be built over the next 10-20 years to accommodate all of their people. This highlights the housing problem, the skills shortage and the capital requirements as drivers for these countries. Separately in Africa, not only are governments dealing with growing populations but also facing large scale refugee and war affected communities

There's a market for these houses. As long as they are built well…One of the major things for me in terms of this market is a lot of redevelopment in the war torn areas…a lot of the houses have been decimated. *I026_MortBeta*

Across the globe there is a massive need for housing. All the companies I interviewed for 3DCP as well as a large number of those I researched are interested in building for refugees and low income communities. It is often mentioned in their mission statements as a goal.

We're currently busy with companies ... in Indonesia, government alone. They are currently in need of ten million houses. *I015_3DBeta*

There is a lot of places where there are no houses at all. And this kind of technology will kind of build new techniques, new villages, new urban areas…So, if and when this takes off, it will be massive *I005_3DOmega*

But at the moment, the main area for actual prototyping of buildings is happening in the Middle East. The Sheik of Dubai has made Moonshot pronouncements calling for the country to move towards buildings to be 3D printed and government-led so that *'by 2023…18% of all buildings, paid for by Dubai authorities has to be 3D printed." (I049_3DAlpha).* Saudi Arabia is also pouring large resources into this technology. There are two reasons for this, growing populations but also a willingness to move Dubai and the Gulf States to prepare form the end of the Oil Age and a move to renewables and advanced smart city technologies. This has resulted in many of the

3DCP companies being involved in projects in the Middle East with several announcing buildings built or to be completed in 2019/20.

I think everyone who works within 3D printing and construction is currently present more or less in Dubai, because we believe that this will be the region that actually commercialise this technology. The sort of the first because the Sheik of Dubai… said that in 2030, 25% of all construction should be a 3D printed. *I017_3DAlpha*

For BIM, the opportunity is to build software platforms that can automate many processes whilst then building out the digital twin concept to enable full data capture of the whole construction process. This is where platforms should emerge and with such a huge market, several companies are currently attempting this, yet none have so far succeeded. Companies such as Autodesk and Microsoft have been building out their software and cloud capabilities, and it will be interesting to see if challengers emerge. If D'Aveni (2018) is correct then current large construction industry companies should start reacting to this disruption to establish platforms to emerge as a manufacturing titan.

Look at where AutoDesk started. They were just a Mickey Mouse little unit that just said we'll give our software away for practically free…Look at them now

I012_3DPAM

But the field is still wide open for BIM software

Software BIM development has not so far been very widespread

I017_3DAlpha

I would say that BIM's definitely an innovation. is it going to be a market generating one? Yes, to a degree. *I010_SoftAlpha*

5.6 Get Noticed

5.6.1 Hype

There's been a lot, a lot of hype. Like there were these guys from a company called Cazza. They're bankrupt now but they promised to build skyscrapers in Dubai by 2022 with 3D printing. And we're like, "Okay, that's interesting. How would they do it?"

I017_3DAlpha

Disruption comes from innovators upsetting the status quo but how do they achieve enough airtime and attention to build a solid base from which to expand. From the interviews, it seems that hype and aggressive marketing tactics can yield short term dividends, but this could be at the expense of future growth prospects for the industry and unrealistic expectations of the consumer and the general population. Most of the 3DCP companies interviewed saw the benefit and risks to using this type of strategy.

They're making massive statements, like Kennedy, "I put a man on the moon" and they only do this in order to get all the governmental agencies, get them crazy.
That's why I'm laughing because he (claimed) 35 m^2 printing within 24 hours. It actually took like four months indeed and then he got this investment, millions, with no customers. *I015_3DBeta*

3DRho and 3DDelta presented time lagged YouTube videos of their 3D construction printers building a house layer by layer and proclaimed that they had could build within 24 hours and cost $10,000. Actually, the buildings took months to build (on the videos it is easy to see the different coloured layers as conditions changed over that time). But as a result, one of them raised $9million from initial investors and is now a leading pioneer in commercialising 3DCP and the other moved to the US and started winning grants from NASA for designs of houses for living on Mars. So, hype can definitely work to attract interest in a technology or innovation. Cazza mentioned above, also raised substantial funds (before declaring bankruptcy) based only on renderings on an iPad. They had only a mock-up of a 3D printer and certainly no prototype for building a skyscraper. Yet still managed to raise funds based on future promises. The new ventures therefore need to understand the potential benefits but also realise the potential pitfalls of overpromising.

There's a lot of hype about this. This is the Gartner hype curve… it basically says that a new technology is coming. Early Adopters are investigating. Mass media starts to write about this. And everybody thinks that now we have a 3D printer in our own houses or 3D printers will build all the buildings in the world. And then people… start to realise, you know, this house was not printed in 24 hours, or no, we will not print skyscrapers in 2022. And then we have a big disappointment. *I049_3DAlpha*

The Gartner Hype curve was mentioned by various interviewees, especially those at 3DAlpha, who use it as a measure of where the 3DCP industry currently is and its likely

future path to long term, widespread acceptance of the technology. The senior executives there believe that 3DCP has recently passed the 'Peak of Inflated Expectations' and is currently on the downward slope in the 'Trough of Disillusionment.' They believe that the massive hype has both equally damaged and helped the industry to gain media and public attention as well as early adopters within the construction industry.

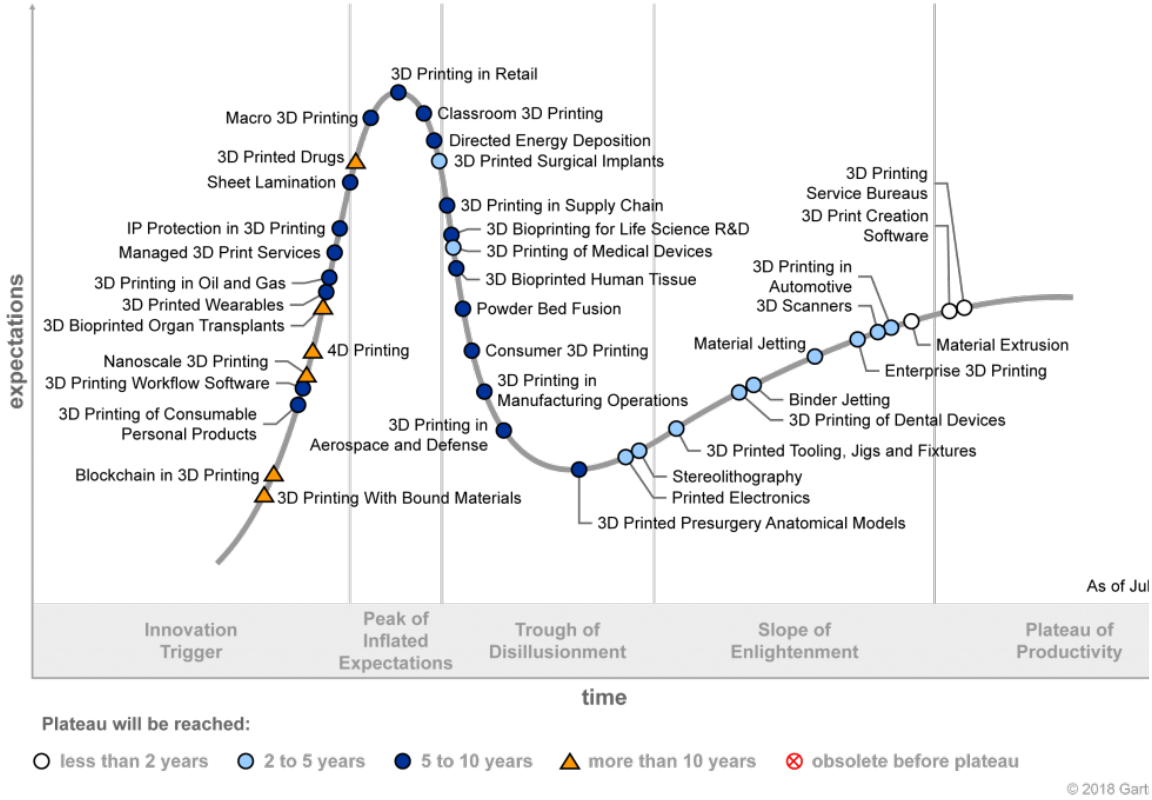


Figure 5.4 Gartner Hype Curve for 3D Printing (2018)

However, using the other 3D printing technologies as forerunners to 3D construction printing gives a good roadmap on how the industry should develop. Gartner has recently produced an updated detailed hype curve for various different industrial uses of 3D Printing (Basiliere & Shanler, 2019). Using examples of other industries such as automotive, medical and dental devices which have now integrated 3D printing as a core process (D'Aveni, 2015), it should follow that 3D construction will emerge from this trough with a more robust and technically evolving business which will greatly impact the construction industry.

The hype cycle model was introduced by Gartner Inc. in 1995 to describe the usual path a technology takes in terms of expectations or visibility of the value of the technology. It merges two distinct curves to arrive at the hype curve shape for new technologies, as shown in Figure 5.4 above. The first describes people's expectations

in the form of a hype level curve. The second uses standard S-curve to depict technology maturity (Dedehayir & Steinert, 2016).
Indeed, whilst interviewing the CEO of 3DPAM a 30 year veteran of 3D printing technology for the aerospace and automotive industries, he also described the adoption progression is similar terms:

Probably with additive (manufacturing), I would say initially it just follows a standard S curve really. So, initially, it was very slow development and things didn't really move much. And then it went through a very rapid increase in productivity, which was function in materials and function of the amount of research being done into it from an educational technical point of view. But, ultimately, now, it's about how much money people are throwing at it. It goes into the S curve, and ultimately, it's a lot of little S curves *I012_3DPAM*

Christensen (1997) believes that substitution can occur even when the new technology is still inferior to the existing technology but Adner and Kapoor (2016a) focus on the time element of when a new technology will supplant an existing one and re-examined the use of technology S curves in relation to innovation ecosystems. They believe bottlenecks in the nascent ecosystem can slow the pace of substitution from emergent technologies whilst identifying how improvements in complementarities can extend existing technologies. In effect incumbents can benefit by making one last effort to stretch their existing technology before transitioning to the new one. Rather than view an S curve based on a single stand-alone technology you must consider the whole ecosystem in which it resides. Again, the whole ecosystem must be ready before it can be successful – the weakness link will delay adoption of the new innovation (See Figure 5.5 below).

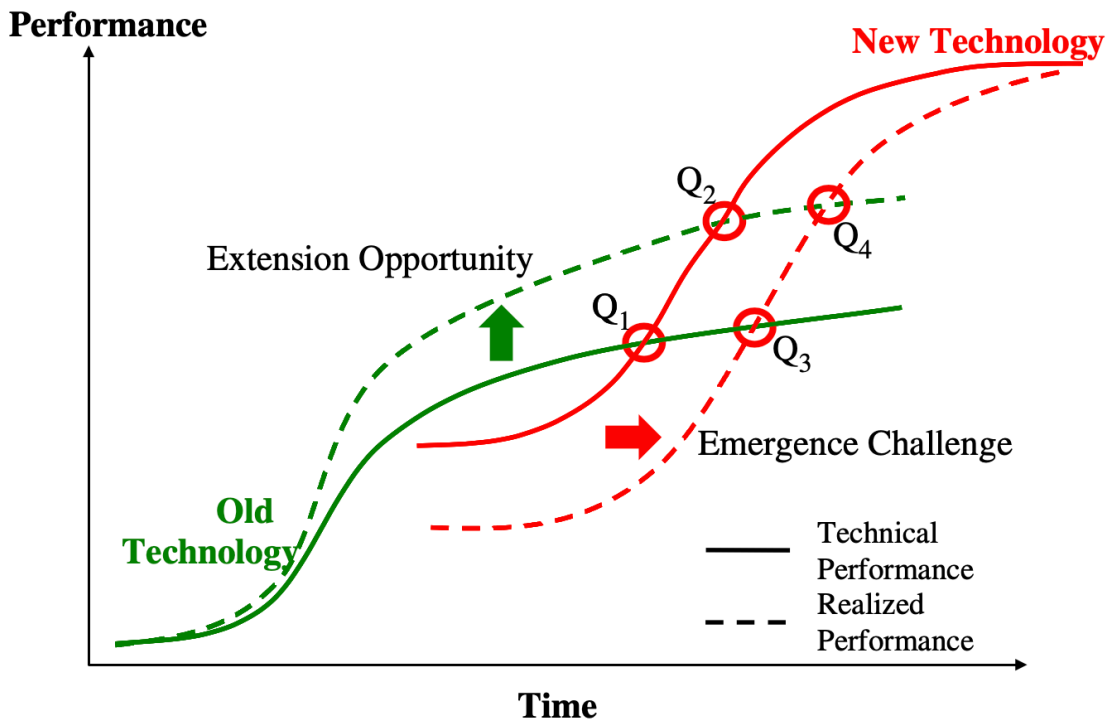


Figure 5.5 Technology S Curves (Adner & Kapoor, 2016a:629, Fig 2)

For the construction industry, as described in Technology of its Time (5.4.2 above) the incumbents have advantages of the enormous size of the sector and the regulatory barriers to ensure they drag out the existing technology before switching to 3DCP in mainstream adoption. Which one will be the weak link in the nascent 3DCP ecosystem is debatable, but changes to building regulation will likely be key. However, the speed of acceptance will vary from country to country, with those that see the greatest market benefits, such as low income countries in need of thousands of houses, more receptive to change.

We are still here: Exploration mode, done by innovators, the market is small, prices are very high, sales are very low, competition is low. And what are we all hoping to get? More awareness, this is really an emerging market. Let's not kid ourselves. It's not mass market, is far from that. We're talking about a new technology curve. Yeah, this is a normal S curve theory, right where it says you have a new technology, you get better and better using it at a certain point, you cannot be to get more out of it. …We're still on this sort of learning curve. And we have no scale effects. *I049_3DAlpha*

In contrast, for BIM the hype has been muted as expected as typical with a sustaining or efficiency innovation, rather than the potential market creating one for 3DCP. Using the analogy of smart phones, it is always more exciting and hyped for a brand new product such as the original iPhone, rather than just an upgrade from an iPhone 8 to an iPhone X. Also, the marketing has been led by governments and industry leaders, so they do not need to use hype to ensure a move to mainstream acceptance. The BIM Levels have scheduled adoption dates. It is also a mature ecosystem where the existing players are aware of the current value proposition and incremental changes are not seen as disruptive but more evolutionary.

5.6.2 Moonshots, 10x Thinking

I asked the CEO, "Why did you come out and say this? You know? That's not true, obviously." "Nah, you know, it could have been true." And there's actually a lot of sense in what he is saying, it could have been true if we didn't f..k up so much…So, in that sense, he was correct…3D Delta came out and say we 3D printed this building in 24 hours and it only cost $10,000. Next day, they had 3 million downloads of the video. Within three days, they got 5,000 emails, they gave up answering them.

I049_3DAlpha

It is apparent that to become noticed many of the small technology companies have embarked on marketing strategies that help promote their innovation but sometimes at the expense of honesty. As one executive put it: "*I think people have been economical with the truth when they've been pushing them what they have reached"* (I017_3DAlpha). The question then arises "is this is dishonest or just painting a future reality?" The company in question that claimed to have printed a house in 24 hours for $10,000 back in 2017, when explaining their pronouncements said that that was their final aim, even if they had not actually achieved it yet.

I went there two years ago to buy their equipment. And when I got there, I found out they really didn't print the house in one day. Four months. Four months (laughs).

I020_3DZeta

In fact, Moonshots and 10x thinking as actively encouraged by start-up influencers such as Larry Page at Google (Levy, 2013) or Peter Thiel at PayPal, can drive an industry towards an end goal (Thiel & Masters, 2014). Taking incremental small steps leads to small improvements whereas large goals can change the mindset of an

industry. For Moonshots or 10x thinking the goal is not to just improve a new product incrementally, but to add 10 times its value or functionality (in effect exponential rather than linear thinking). Even *I015_3DBeta*, when describing the hype, still used the analogy of John F Kennedy's goal to put a man on the moon. Now it has been achieved it obviously seems achievable, yet in the 1960's the list of ostensibly impossible hurdles to overcome would have been a much more daunting challenge. Only by bold thinking and stretch targets can the seemingly impossible become probable. In fact, the explosion of interest in 3D printing, including for construction, has been turbo charged since the Sheik of Dubai announced the intention to be a centre of 3D technology and has set up innovation labs and research centres to promote all kinds of innovation, and set demanding stretch target, even if it is not exactly clear on the specific performance metrics that need to be obtained. The Middle East is currently the global hotbed of 3DCP innovation and progress as a result with several recent announcements such as the largest commercial structure, a two storey office building completed in December 2019 by Apis Cor (See Figure 5.6).

The Sheik of Dubai … said that in 2030, 25% of all construction should be 3D printed. Exactly what that means specifically, this really is it's not been specified

I017_3DAlpha

Dubai and Saudi Arabia are definitely the leaders in prototyping innovation in construction using 3D printing. At the end of 2019, almost all the companies interviewed, and a large overall portion of the companies analysed had invested in showcasing their technology there. From initial small 35m^2 buildings in 2016, progress in 3 years has been rapid. Especially as this building has 9m high walls and was constructed using one machine and only 3 men.

Figure 5.6 World's Largest 3D Office Building (Apis Cor 2019)

5.6.3 Proof of Concept

For this to work, there needs to be some form of prototype on display in the country…A prototype house on the ground that can explain, physically, all of these issues that I raised will be very helpful *I006_AfriHouse*

It requires more than clever slogans to convince the general public and especially incumbents in a traditional industry such as construction. Almost all the interviewees, whether positive or negative about automation and innovation, wanted to see a proof of concept, either a printed building or a simplified process management software tool, utilising a concept such as BIM.

I need to see. It would need to understand it. Will all be proof of concepts?
I026_MortBeta

What we are doing with other technologies is providing space for some samples and more sort of like we have sites, kind of do that crazy, a small plot style, a few homes if you will, to see how it works *I032_SovFund*

This has been recognised by both the 3DCP companies and BIM software suppliers and all of them had been focusing on demonstrating their technology. For the 3DCP companies this required a proof of concept house to be built. Of those 3DCP companies interviewed there were clear leaders in the industry, and it was obvious that the ability to showcase an actual house was key to that.

The proof of concept. Yeah, that's been most important, that we actually built a house…It's here, it's a physical thing. So, it's not just a promise anymore
I017_3DAlpha

It's like everybody asks the same two questions, is, "Have you built one yet?" and "Can you get a permit?" So, we're building on a very difficult lot, and we're doing that to showcase the technology *I020_3DZeta*

We did the building to prove that our technology worked. And, and we will do other projects in the future for the same reasons. *I049_3DAlpha*

Companies such as 3DAlpha and 3DBeta since building their first houses in 2018 have leveraged their prototype houses to win commercial orders and to attract partners. But

it is clear that much more is required if this industry wants to go mainstream. So far only 20 houses have been built (as of end 2019). Yet almost 50% of a construction conference's attendees have seen websites and YouTube videos demonstrating them. Time capture technology and other presentation tricks have allowed these companies to present a great narrative of the technology and within the next 12 months (in 2020) there will be an exponential rise in the number of houses and other construction projects utilising 3DCP technology. What was a theoretical concept before the first house was showcased in 2016 has now been proved and the companies are now focusing on overcoming technical issues and moving from a knowledge to a business ecosystem.

Conclusion for this point is that we have proven the potential. So, we have shown that is definitely savings to be made there. That is market potential. And there's definitely a way into doing this. But we need to do more projects, we need to learn more, we need to get out there and do it. So that's what we're doing *I017_3DAlpha*

5.6.4 Financing

"We want to do this. We want to do this," so, "Okay. Put up some money," and you never could get them to put up any money. *I020_3DZeta*

As these companies develop their product, they either become the keystone leaders or influencers in that new ecosystem (Iansiti & Levien, 2004b) or need to decide if the ecosystem they and their community are building a structured ecosystem or just an affiliated network of companies (Adner, 2017). The proof of concepts allows a starting point for the companies to engage in discussion with early adopters to move to the next stage of development. And this can prove difficult.

There are some early adopters we're talking to. One of our large customers is just started going down that prefab route. And we are talking to them, well what's it means in terms of how we're going to help you service sites *I002_SoftAlpha*

It was slow…you know you have to convince that first organisation to go, to go with it. I guess they pilot, they start small. And they try it out maybe on one division.
I004_SoftAlpha

Even with a new product such as software or a 3DC printer, both require early adoption by existing or new customers, and both require investment or orders to allow the pilot projects to be completed. Reflecting on the experience in other 3D printing industries, it proves hard to build financial backing and the network of partners in the ecosystem.

If you don't get anybody to fund you, it's a big problem and that certainly was a big challenge for me all the way through with 3DPAM was that getting funding to grow the company was a nightmare. It all had to be organic and that really does make life very difficult. *I012_3DPAM*

In response to both the challenge of finding finance and also to build initial customers, many of the new companies in 3DCP sought out government and industry research grants to help them build prototype machines and projects. Of the companies analysed, both through primary and secondary data, there was a large proportion of firms that initially relied on government or university research grants in order to progress their technology until they could then build out their wider ecosystem or network. This again highlights how new ventures benefit from first being part of a research or knowledge ecosystem before moving to commercialise their product. It also points to the importance of larger players such as governments or government sanctioned research bodies, like Innovate UK, to play a key part in advancing key new innovations in a traditional and slow moving sector. Although the construction industry's transformation will likely be led by the private sector, governments play an important role, by pursuing policies that incentivise the adoption of innovation. The World Economic Forum (WEF, 2017) see three key roles for governments to play; (1) as a smart regulator to update and harmonise building codes; (2) as a long-term strategic planner with a country level innovation agenda investing in flagship projects and R&D; and (3) as a project owner seeking to innovate the whole lifecycle of the buildings.

It is in its strategic planning role that the government can also act as an incubator for small innovate firms to provide financing and advice. This can be seen in research bodies such as Innovate UK.

We applied for some government grants for researching this. We actually got a 3 year grant for researching state of the art all 3D construction printing globally with the aim of bringing that information about the state of the technology to the construction sector.

I049_3DAlpha

But several participants saw the process of winning a grant as a flawed system with many of the larger grants going to large incumbents with a wider set of capabilities. But this also means they have traditional thinking biases and may not be the best or most innovative people to take these new technologies forward. In a challenge to the findings by Clarysse *et al.* (2014) who believe that policy should give grants to larger industry leaders as well as start-ups in knowledge ecosystems, this runs the risk that the smaller companies are frozen out. 3DOmega when applying for grants through Innovate UK was rejected on the grounds that a senior construction company was not yet involved in a proposed proof of concept project.

Even an Innovate project, if you're a small company, you don't have the capacity to actually run one of those projects in terms of the managing of the project. So again, I think you tend to find your large construction companies tend to dominate getting hold of the money, because they have the capacity to actually be able to manage them. But, of course, they're not necessarily the sort of people that will do the manufacturing.

I011_UniBeta

This brings us back to the benefits of a collaborative ecosystem approach rather than relying on the internal dynamic capabilities of the firm (Teece, 2007). Large incumbents have a vested interest in defending their position, but also are more inclined to keep to traditional business models and methods of manufacturing leading to small incremental gains rather than market creating ones, if they are left to lead the projects. The research universities that act as a conduit for the grants in knowledge ecosystems and the most likely to allow smaller ventures to be treated as equals should adopt an open innovation strategy (Chesbrough & Appleyard, 2007) and make sure that the larger companies do not suppress the moonshot thinkers when a research grant funded project is being assembled. Otherwise a rich source of fresh innovative thinking for the construction industry will be missed. However, in other countries the smaller companies have been able to utilise the grant process, as a method to build their initial knowledge ecosystem, through universities and research bodies and attract like-minded early adopters and innovators. The companies that are at the forefront of the 3DCP technology in terms of actually printing a proof of concept house have almost all had a research partner (typically a large research university) to enable them to showcase their work through a proof of concept project (See Table 5.1 in 5.7.3 below).
Apart from the small 3DCP companies, most of the remaining ecosystem players involved in this research were medium or large organisations that could utilise a strong connection with an existing client to help finance a pilot case. But even here they relied

on the skillsets of others such as the BIM software companies, who relied on Microsoft or AutoDesk to provide key components and complementary functions to their developed software. Cloud technology that has been developed using a vast IT ecosystem can be harnessed to advance at a smaller industry or software community ecosystem. This allows a Silicon Valley type approach to fail often and fail quickly in order to ensure a steady stream of innovative ideas are given a chance but any that do not provide a market benefit are shut down quickly.

I am less interested in the amount of stuff that you build; I am more interested in the amount of stuff that you throw away. Because unless you are throwing lots of stuff away, you are not moving fast enough. *I051_SoftGamma*

But as with anything in life, without investment of time, money and resources, the technology cannot be developed. When the investors take an interest as it starting to happen with large construction companies now taking notice and partnering with the smaller new ventures, so the speed of development accelerates, and the disruptive innovation can reach parity to the existing technology quicker.

With funding comes better technology. And that's what I said before, if more funding was being provided, then the technology will be developed, and it will outcompete the conventional construction industry. *I049_3DAlpha*

5.6.5 Education, Training, Marketing

You've got to hard sell. It's not just bringing the technology and then making it and thinking that's great, at the end of it somebody's got to buy it... If people don't like it, you're not going to sell it. *I019_WoodGamma*

Being traditionally slow to change, the construction industry may appear unreceptive to innovations or ill-prepared for them. Successful innovators need to inform, educate and train incumbents on the new innovations. They need to partner with players who can act as agents to promote their technology or set out to educate the market through demonstrating the technology (WEF, 2017). As discussed above regarding Early Adopters Risk (5.3.3), being an innovator is not enough in getting a new technology or process to market. There are reasons why a firm may want to be a first mover or wait to enter as a fast second mover (Adner, 2012; Teece, 1986; 2018b) There is the advantage of moving first to shape the ecosystem through innovation and collaboration

and the ability to act as the focal firm in the ecosystem (Teece, 2007; Teece, 2018a) which was corroborated by the findings:

We realised that nobody was actually talking about building a house in Europe. Then we're like, all right, let's do it. It was like, yeah, we could, we had an opportunity to be the first and to get a lot of media attention from that and so on. And then we just built the printer and tried to print construction material. We went out and marketed it and obviously we knew a lot of the partners within this field because we had done the research before. We followed all their progress very closely to see if we had any competitors to take this title. We figured out the date they wanted to start. And we just set our deadline a week before and then we just went for it. I017_3DAlpha

There was also a wide acceptance of the risks of being a first mover unless you have completed the assembly of the whole ecosystem and devised a bottleneck strategy (Hannah & Eisenhardt, 2017). There is a tension between wanting to be first in order to get the media coverage and brand recognition, before fast imitators enter the same marketplace versus securing your innovative ideas through protective patents and legal agreements.

So nowadays a lot of SME's going to be first to market…They recognize they only have a limited window of opportunity to exploit to it before somebody pinches it and runs off with it I043_UniAlpha

This has already happened in the 3DCP sector, even before the industry has left the concept adoption stage, with a lack of intellectual property (IP) protection for the enabling technologies as patents need to be protected across international boundaries, but this can be difficult to achieve in practice (Teece, 2018b).

Well, I know how 3DXi did it. 3DLambda just got patents for the U.S. And then, 3DXi followed their patents basically, and then patent it in (other country)…, and then made a billion dollars from the Saudi Arabians, selling plants. Just like "Whatever!" I020_3DZeta

So, there is a fine balance to be juggled between opening up to a community or end users to gain financing, investors and clients against the risk that other companies clone your ideas and aggressively market them themselves in other countries or areas. The concept of open versus closed innovation strategies is discussed in more detail in

the next. So back to the question of marketing to raise awareness without losing control of your competitive advantage. This is fraught with issues as new technologies need explanation and that takes time and resources. It leads right into the heart of the ecosystem concept where players are interconnected to a common value proposition (Adner & Kapoor, 2010). Should you market on your own or in conjunction with others? Using the ecosystem helps to utilise the strengths of the group and allows for smaller companies to piggyback on others "*in effect, getting their sales and marketing for free" (I019_WoodGamma).* This is vitally important for small ventures who have limited dynamic capabilities to throw resources into marketing efforts. Especially as marketing a new technology will take time to educate customers and the wider public.

I would say probably 60-70% of sales teams' time was spent just explaining the technology. Time and time again… it's been a very big educational challenge.

I012_3DPAM

However Overholm (2015) discovered that the negative effects of educating other ecosystem players, which limits the focal firm's value creation and the initial ecosystem value is mitigated by increasing the total size of the market, so in effect all boats can float on a rising tide. Within the construction industry 3DCP companies face more challenge from competitors in competing innovative technologies rather than from the community of pioneer firms within 3DCP. For BIM, the top down ecosystem with government as the current keystone player, it faces a different challenge as it needs to educate a much larger ecosystem, where a large percentage of the players within that ecosystem may not be as enthusiastic about the technology and are being unwilling participants as opposed to the 3DCP bottom up ecosystem where all participants are genuinely interested in developing the technology.

I showed him a 3D model of the houses and he went, "Oh, it's, BIM. Not for us". (Laughs) and now we are starting to see it. But they're only very early days of introducing it. *I014_WoodAlpha*

When resources are scarce companies have to make hard choices on which business avenues to follow (Pfeffer & Salancik, 1978). For smaller new ventures, the time spent educating potential customers and other early adopters can overwhelm the vital activities in other areas to develop the technology further. The experiences of the other incumbent firms on their growth path, suggest that new ventures in BIM or 3DCP

should make an early choice on who to partner with, or risk wasting time and money on those who maybe affiliates rather than core structured ecosystem partners.

I'm trying to get our sales team to not deal with customers that don't know what the technology is, because it's a waste of their time. There's plenty of people out there who understand enough to at least be kind of on stage two and start thinking about their strategy for using the technology. So that's just one of those big challenges you got to be hard-nosed about it and not waste your time on people who that aren't gonna be spending the money with you. We did far too many years of that, really.

I012_3DPAM

It's very rare these days, that I would go into a virgin patch without the client wanting to do it. I won't be going in, it's a waste of time to try go to the developer who's built all his life in masonry. And, we are there to try and sell them timber frame. Forget it, it's just not worth it. *I014_WoodAlpha*

The potential customers for both 3DCP and BIM involved in this research all expressed a need for training and education of the workforce, alongside any marketing of the technologies to businesses. A real issue will be the disruption in the existing workforce as these new technologies require a greater skillset than many traditionally labour intensive roles. Kothman and Faber (2016) expect the demand for low-skilled workers to decline due to automation whilst demand for high-skilled workers familiar with the new technologies will increase. Labourers' resistance to change and high levels of turnover at the bottom end of the industry (Labonnote *et al.*, 2016) as well as trade union resistance to job losses will be challenges the disruptors will face.

It's been an issue where you have some new technology, the content that we would like to do. You know, you don't find the skilled labour for it or the personnel

I027_DevAlpha

One of the things that that's affected the introduction of even the evolutionary building technologies in (Africa) is a lot of our workforce have been trained for many years used to the traditional brick laying. So, the mindset of accuracy from the beginning is not there *I032_SovFund*

One of the 3DCP firms, 3DEpsilon, has now decided to look into 3D printing of chocolate rather than concrete buildings due to issues with local builders in the

Philippines after he showcased a 3D printed hotel room. When they realised their jobs would be replaced by the technology, he had to flee the country quickly in fear of his life. It is only through open education with potential users of the innovation and potential retraining of existing workers, will a foothold be established in the existing sector. For low cost countries, it may at first appear that the cost of the machine cannot compete with the cheap labour, but the machines are designed to work for 15-20 years and will deliver a much higher quality product. Whilst cost is currently still a bottleneck, once it reaches parity or sub parity to traditional methods then quality will be the next benefit.

There is a capital investment in the technology itself, but also significant training and development for your workforce. Otherwise you do the panel perfectly in the factory and the guy who has to go onsite makes a dog's breakfast of it. *I032_SovFund*

Education and training also widen the ecosystem players as it opens up to a wider range of agents, such as design houses and architectural institutes to become disciples of these new innovative technologies. Key partners are research universities with enthusiastic youthful students and graduates, more open to new ideas. Those marketing both 3DCP and BIM seem to have realised that they need to educate clients and that this is a key requirement if they are to gain acceptance as a new technology and to find key employees who can work for the firms.

Also, with partners that we work with. We educate them, we focus heavily on education with 3DBeta Academy. *I015_3DBeta*

The companies understand that they cannot be onsite for all the pilot projects as they have not the resources to cover them all. Instead they are embarking on full training programmes, open days, demonstrations as well as providing manuals. 3DZeta requires a full time intensive two week training programme on the equipment as part of its sales strategy. By providing this training they eliminate the risks of misuse of equipment resulting in shoddy buildings that may undermine the nascent industry, as occurred in the timber frame sector.

We have a full manual, it's actually online as well. It's on the website. So, we have to do some training manuals. Just like, it's user manual, you could say. So that's like step by step processes of that's like everything that should be in a CE certified machine.
I017_3DAlpha

We need to set up a training program so I'm documenting it every day, how many people were on site, what did we use, what have we accomplished, pictures, all that sort of thing. *I020_3DZeta*

In summary the new ventures seem to have learnt from the mistakes seen in other adjacent technologies and are investing time and effort to ensure they do not suffer a similar fate. Whilst there are still concerns as to the negative aspects of innovation in the construction industry, such as the environmental impact of concrete and the loss of low skilled jobs which need to be addressed and quantified, the benefits as highlighted above, are being emphasised through education and training.

5.7 Vision & Business Model

5.7.1 Being Disrupted

Our business model was to move ourselves from the low end, to move into middle end, upper end. They're still going to need things and they carry on spending. When it becomes a commodity, you're in trouble. And that's what happened to us. The price got driven down, so when they took us out, they were taking us out of the market to maintain their market share. *I019_WoodGamma*

Disruptive innovation as defined by Christensen (1997), describes how incumbents are displaced by new ventures who initially target the lower end of the customer base. What was interesting, is that many of the interviewees had experienced this, as shown in the quote above.

Even for the 3D printing companies, who could be described as the new ventures and disruptors, they also recognise the dynamics at play:

I think that still holds true and the people who will win will be those who come up with the best innovations in critically beneficial areas for additive and then they all get so good at it that other people find it hard to compete. *I012_3DPAM*

Whether this is a function of disruptive innovation now being ubiquitous, with Christensen himself arguing that after nearly 30 years the concept has been used to describe any business change (Christensen *et al.*, 2015) it's now overused and an easy go to in times of change for whatever the real underlying reason. But the interviewees had differing opinions about what innovation actually meant and whether it was being seen in the construction industry and to what end.

I made this bold statement that an innovation cannot be an innovation unless it adds value over a medium to long term to the person that's on the receiving end of the innovation. *I010_SoftAlpha*

I think we need to be careful with innovation, moving product forward, making changes for the sake of making changes. Because what we do at the moment does work. You've got to question how the innovation's going to fit in. There has to be a win-win somewhere *I019_WoodGamma*

What is interesting is that most of the participants recognise that innovations need to provide a benefit, otherwise they are pointless. This chimes with the other questions regarding what benefits were the most important to them in terms of innovation in construction, namely cost, cost, cost! This idea was seen in many of the interviews, especially with the incumbents, who although they could see that change was coming, not all of them were positive about how it would impact the sector and who would be the driver of the change. And whether it was actually innovation or just change. Whilst I had started out thinking I would see a common vision on 3DCP and BIM being market creating innovations, in actuality most participants viewed both of them as either efficiency or sustaining innovations. Perhaps this could have been expected for a process like BIM, it was definitely surprising for 3DCP. But in effect they only saw it as a way of reducing cost and the manpower required to build with traditional materials.

I don't think BIM is an innovation. BIM is just a methodology that people should have been using it and actually they know they should have been using it for the last 50 years because of cost and laziness *I010_SoftAlpha*

In total there were approximately the same amount of positive comments regarding the innovations as there were negative or neutral ones. Positive comments tended to be around cost and efficiency with changes to building practices:

We're trying to force through a significant change in the house building market in terms of the cost of building…to force through innovation in construction, innovation in pricing *I032_SovFund*

You're no longer theoretically going to have bricklayers on site building houses. You will have people with spanners and socket sets coming and bolting them together. A lot of the house builders are only just starting to understand that themselves

I002_SoftAlpha

Negative or neutral comments tended to be around whether such a vast industry could ever be a hotbed of innovation:

I don't see in our markets 3D printing as a serious threat… people are talking modular quite heavily…I've not seen it at the moment really. It's such a traditional industry and I don't think it's open for disruption, but I think people have tried it many times before... can't say it's never gonna happen but, it's highly unlikely. *I014_WoodAlpha*

Innovation in our marketplace is encouraged, but normally priced out, because everything is price driven. *I018_WoodBeta*

Several referred to previous attempts with offsite prefabrication (modular housing) and timber frame, which were launched decades ago but have not seen mainstream adoption.

In the construction industry when offsite manufacturing has been around from the late 1980s and it's still not taken off in the mass market. *I010_SoftAlpha*

The big builders have all done trials with the modular build…but I haven't seen, not aware of any that have really gone, "okay now we have this modular build product" that they introduced somewhere else. I just don't see that. *I022_ConstructAlpha*

Existing research focused on examples of large firms that fail to react to disruption such as Kodak (Ansari & Krop, 2012; Lucas Jr & Goh, 2009; Teece, 2018b) finds that senior executives being either blind or not concerned with disruptors and new innovations pushing them out of their market, or as shown here they can see the changes coming but are slow to recognise the threat. The incumbents interviewed whilst acknowledging the possibilities of change, did not view them as immediate threats or even in the medium term. However, if the whole dental teeth aligning and hearing aid industries can convert to 3D printing within a couple of years (D'Aveni, 2015) then in the old adage written by Ernest Hemingway: "*How did you go bankrupt? Gradually, then suddenly"* (Hemingway, 1926) comes into focus. Nearly a hundred years on it still seems to hold true, perhaps like the fable of the boiling frog, change is

too slow for incumbents to react to until it is too late. It appears to hold true based on this research which therefore leads to disruptors having both the opportunity to develop their technology according to disruptive innovation theory, and nibbling away at the incumbents unnoticed or ignored, whilst they gather knowledge and build their ecosystem, and emerge later to dislodge the incumbents over time.

Another way to consider this is as Ansari *et al.* (2016) requested as an area for further research, "*how does a disruptor generate a vision of the future that is compelling enough to persuade incumbents to support its innovation despite the clear and present threat of disruption?"* I add to this a question for a large traditional industry such as construction then, is '*who disrupts?*' If disruptive innovation theory holds true, then the incumbents are mainly only engaged in sustaining and efficiency innovations whilst disruptors, typically but not always small new ventures, are focused on market-creating ones (at least to begin with). From this research, opinions differed on whether it would be a new venture or an incumbent. Recent entrants to the modular housing (another potentially disruptive innovation for construction) include Legal & General Insurance company. They have built a £50million facility near Leeds to start producing modular homes for affordable housing developments. As this is an insurance company what does it know about house building? Could it be that incumbents are still not reacting to new entrants coming into their sector?

I think it'll be an innovator. I mean there's companies like L&G that entered the marketplace, so that's a real departure. An insurance group recognising that this demand for housing, putting together a completely new team, new innovation.

I018_WoodBeta

But the start-up costs are huge for modular housing compared to the relatively low costs for small 15-20 man ventures so far seen in 3DCP companies. Yet several interviews thought that only those with deep pockets can really disrupt quickly:

L&G up in Leeds. Invested 50 million... you know that as an investor, you've got to be mad to invest 50 million in an offsite manufacturing business. You're just being mad; you'd just be burning cash. *I014_WoodAlpha*

Disruption will start with the incumbents in places like Nigeria, India, China because it's the State that's going to do it for housing in that somebody needs to say "there's a hundred billion pounds…We're going to build 100 million houses"

I047_DoorsAlpha

But when speaking to the new ventures, their mindset is completely different. They see the challenge but also the opportunity. They are embracing the new technologies and putting them to use. As seen in other industries, these small nimble start-ups do not carry the baggage of larger firms nor the legacy investment costs building up their business. They also see the changes being mandated by governments through BIM and how this technology can simplify and digitalise what is still seen as a labour intensive sector.

I'm representing some of the disruptors out there…the construction industry is ripe for disruption by 3D printing companies *I049_3DAlpha*

If you go to do digital transformation, you need to think big, and keep thinking big
I051_SoftGamma

We should be all going to a digital construction process
I020_3DZeta

What we do is high-tech, playing not only with printing, with robotics, but Internet of Things, parametric modelling and then we change actually the entire supply chain.
I015_3DBeta

What is interesting is they also recognise that a pathway for them will be to partner up with a larger strategic player and become the skunk works or moonshot factory of that firm. This represents the same thinking seen in Silicon Valley used to change industries through big bang disruption techniques of ripping up the conventional playbook (Downes & Nunes, 2013).

They have a hard time in those big companies to actually develop new technology for real, and actually pushing. So, they set up this Moonshot Factory
I017_3DAlpha

Again, it comes down to the community that the new ventures surround themselves with and what drives them. For BIM a top down directive from the key player, the government, forces them to change but will likely to be incrementally and as an affiliation to the value proposition whereas the bottom up organic approach for a community that are all enthusiastic participants in developing something new can be described as more of a structure around the value proposition (Adner, 2017).

5.7.2 Business Model Innovation

The real practical barriers to innovation are the mindset and the business model.

I010_SoftAlpha

As described in Chapter 1, a business model "*depicts the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities.*" (Amit & Zott, 2001). New companies use business model innovation to find new and innovative ways to create and capture value (Casadesus-Masanell & Zhu, 2013) whereas incumbents innovate to adapt their existing business model rather than to invent it from scratch (Cozzolino et al., 2018). It is recognised that construction industry companies need to embrace business model innovation alongside technological innovation and can do so by redefining the contracting and procurement processes, through early collaboration and a fresh look at the lifecycle value of the project, rather than just focus on the initial lowest cost bidder which is typical of the current process (WEF, 2017). This research finds that participants are aware of the need for change and to adopt practices already ubiquitous in other industrial sectors:

If you look at other sectors, automotive, aerospace, mechanical engineering, they sorted out their 3D model formats back in the 80s. And everyone drove forward with that pushed all the way up supply chain… *I048_SoftBeta*

After conducting the interviews and coding them, it becomes clear that technology is not seen as the disruptive innovation in the construction industry. There are many technologies emerging, from augmented reality headsets, to automated diggers, to 3D printers. And similarly, it is not just the CAD software that designs the buildings, nor the iPads to display them, nor the BIM software to record and store this digital twin that is seen as the disruptive innovation. Instead it is the combination of all these technologies and complementarities in a novel business model that represents the real market creating innovation. It is business model innovation that will really shake up the construction industry, whether driven by government mandates or by small venture disruptors.

In line with the BIM thinking, this is all digital, we need some digital input to actually get a physical product…It starts with that we have an input file...put that into your computer

and to your programme…all based on digital data, then transformed into a physical product or product. And this of course, can also be combined with the visualisation of planned new building. *I049_3DAlpha*

Amit and Zott (2012) cite the Economist Intelligence Unit who found that 54% of senior managers favour a new business model over a new product as the source of future competitive advantage. Yet within many organisations business model choice is often overlooked or unchallenged as a method to create value. It is much harder for a competitor to imitate a whole ecosystem than it is to imitate a particular product. Whilst it is hard to do, it can give outsized rewards such as Nespresso and Gillette switching their business model from manufacturers to an ongoing relationship with customers. Gillette sell the razor cheap but have ongoing business selling you the blades. Nespresso sell you the coffee machine then a monthly supply of coffee pods (Amit & Zott, 2012). Again, this needs a holistic ecosystem approach with a range of complementarities to be successful. BIM offers a chance to do this if the incumbents can all adopt it.

It's not that far off, but it's centred around the BIM model. The BIM model is basically you've got a single source of model, single source of document, single source of tasks, high accessibility from contractors, the building owners, the engineers, to the project managers, to architects: all that look at that digital picture…We're working on this right now. *I020_3DZeta*

What is apparent is that whilst BIM represents one end of the ecosystem spectrum, a top down approach directed by a government or industry champion which is trying to see adoption by current incumbent firms, the small new ventures for 3DCP are looking beyond just the technology or software and envisioning the whole supply chain being innovated. This confirms the literature on 3D printing (Labonnote *et al.*, 2016; Laplume *et al.*, 2016) that sees Porter's global value chains (Porter, 1980; 1985) being condensed and the creation of new localised models. They see that BIM represents a bridge that links their disruptive technology innovations directly into the existing infrastructure of the construction sector and can be utilised to fast track them into its heart.

Everybody's looking at it from the technology standpoint of just a machine, and I'm looking at it in a broader scope, to say, "We need to change the business model"…And

that's what I'm working on. I mean, to me, that's going to be the technology changer, is the whole business model. *I020_3DZeta*

It's not only about the printer, it's the entire concept of design, engineering, the hardware, the software, and the material of the printing technology…We are a technology provider…it's about concept. It's not about printing. People want to have a house being built fast and affordable. *I015_3DBeta*

Condensing these ideas into a single framework is obviously beyond the scope of this research study but gives an idea on how to start 10x thinking, I illustrate a simplified version of their vision for the future of housebuilding as represented in Figure 5.7. In this scenario a platform manufacturing titan has emerged, he connects the end user (the house buyer) to the 3DCP company (the builder) via his digital platform. All the design is done digitally to the client's specifications, structurally checked for building integrity before being transferred to the printer onsite at the same time multiple procurement orders are dispatched to arrive in a timely order. Then 'hit go' onsite to build.

We're looking at BIM systems at the centrepiece…and we're going to build our systems around the 3D model, open-source model. *I020_3DZeta*

When we do 3D printing, we go directly from the BIM software to the construction, which means we have a digital bridge from our design software into our actual physical objects or house, wall or whatever *I017_3DAlpha*

The platform provides a full breakdown of components required, delivery times, costs. The BIM software records the whole process from design to handover and provides a permanent record, stored securely using unique blockchain technology, for the client. This is a customer centric, open platform featuring limitless designs, faster build times, no waste, with full digital records easily accessed for maintenance teams to understand how it was built, how to repair it and how to recycle components. A digital file that can be given to the homeowner and passed on and updated in real time containing its full lifecycle from design conceptualisation through to end of life recycling on an open standards platform. This *digital oracle,* open and shared with all ecosystem participants can move housebuilding and society towards a circular economy sustainable process. This is the moonshot vision even though these companies realise that at this present time the 3DCP industry is at Stage 1, Concept Adoption (D'Aveni, 2018).

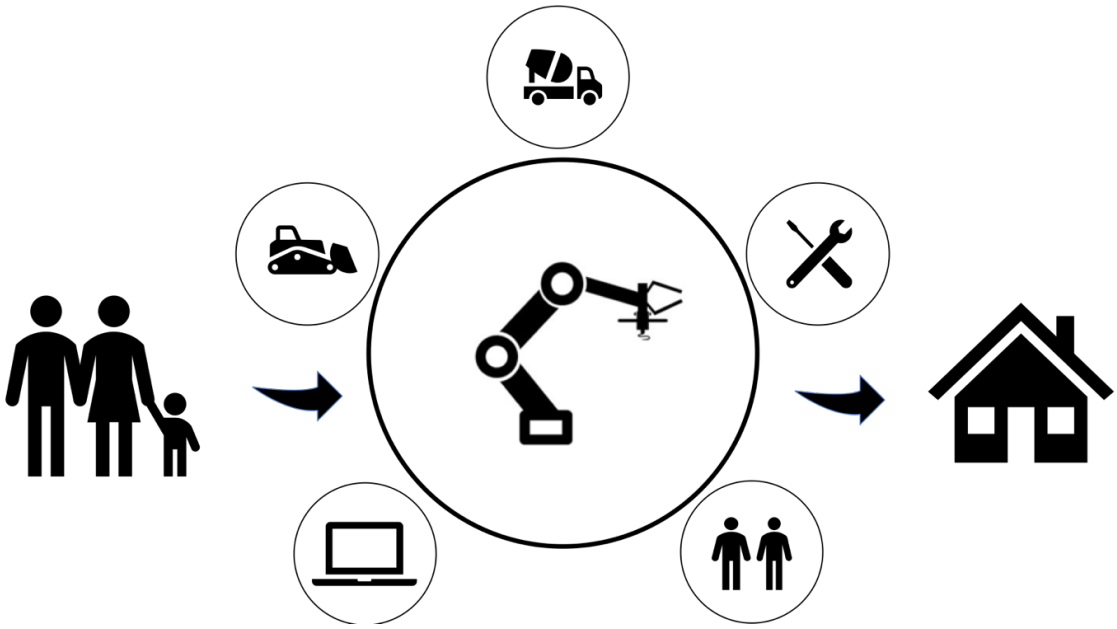


Figure 5.7 Conceptual House Building Process

Although currently still in the knowledge ecosystem yet to be commercialised into a platform or business ecosystem, the drive to innovate will attract new players to construction and remove some of the existing barriers to entry as they emphasise an open innovation strategy. As new ventures with different mindsets come into the sector the culture can change and a better platform can emerge to build a new cost efficient industry that provides better medium to long term value for customers especially the non-consumers in need of decent quality and affordable housing.

I can see that focus is beginning to change in some sense towards where can we find innovative solutions towards kind of unlocking the restrictions around the demands and pretty much like a closed off market. I032_SovFund

We want to make the process, particularly construction easier and safer. The other part was to streamline and speed up the process…if you get to a production system going you get a much more manufacturing approach I050_ConConsult

Using the lean manufacturing processes already seen in other industries and incorporating them into the BIM process and digital twins' concept, can drive down costs across the sector whilst simplifying the number of steps needed in the build process and remove the inaccuracies and waste seen on today's building sites.

Companies in the construction industry need to build effective collaboration and the dissemination of knowledge beyond company boundaries in a sub sector or industry ecosystem. The 3D-printing start-up MX3D, building a metal 3D printed bridge in Amsterdam, views its success in its collaboration with prominent companies across traditional industry boundaries, to bring in expertise in robotics, welding gases, metals, design software as well as construction to work alongside MX3D's development of robotic autonomous 3D-printing software (WEF, 2017). This highlights how new ventures, reaching outside traditional construction companies, can drive business model innovation much faster as well as illustrating their willingness to seek innovators from many backgrounds.

5.7.3 Construction Workforce Innovation

Strikingly, the backgrounds of the 3DCP companies' founders is heavily weighted towards technology rather than construction. Even those with construction backgrounds exhibit entrepreneurial attributes as black sheep and mavericks, such as the founders of 3DBeta and 3DZeta. Few are lifelong construction journeymen. But without a background in construction or robotics, entrants are unlikely to be successful in 3DCP as partners will require evidence of expertise. However, recent literature points to the emergence of a new type of 'digital engineer' for the construction industry (Russell, 2019) which highlights the skillsets required to build the houses of tomorrow are more likely to be digital rather than the current manually intensive ones. Incumbent firms need to be aware of this trend and act accordingly. Human resource managers at these firms should establish methods on how to hire an innovative workforce (Hunter *et al.*, 2012) and train their senior executives on leading these clever people (Goffee & Jones, 2007).

Table 5.1 3DCP Company Information and Partners

Company Name	System	Founder Background	Concept House	Main Strategic Partner	Research Partner	Collaborators	Open Innovation (5 highest)
3D Alpha	Gantry Extrusion	Technology	Yes	Yes	Yes	Yes	5
3D Beta	Robotic Arm Extrusion	Construction	Yes	Yes	Yes	Yes	3
3D Delta	Robotic Arm Extrusion	Technology	Yes	None	Yes	Yes	2
3D Epsilon	Gantry Extrusion	Technology	Yes	None	None	Unknown	3
3D Gamma	Gantry Extrusion	Technology	No	Yes	None	Unknown	3
3D Kappa	Gantry Extrusion	Technology	Yes	None	None	Unknown	5
3D Lamda	Gantry Extrusion	University	No	Yes	Yes	Yes	4
3D Phi	Gantry Extrusion	Military	Yes	Yes	Yes	Yes	4
3D Rho	Gantry Extrusion	Technology	Yes	Yes	Yes	Yes	3
3D Si	Gantry Extrusion	Technology	Yes	Yes	None	Unknown	3
3D Sigma	Robotic Arm Mesh	Technology	No	None	Yes	Yes	3
3D Tau	Robotic Arm Extrusion	Technology	No	Yes	Yes	Yes	4
3D Theta	Gantry Extrusion	Research	Yes	None	Yes	Yes	4
3D Var	Powder Bed	Technology	Yes	None	Yes	Yes	4
3D Xi	Gantry Extrusion	Construction	Yes	Yes	Yes	Yes	3
3D Zeta	Robotic Arm Extrusion	Construction	No	None	None	Yes	3

I also highlight several other findings which are discussed below on the ecosystem partnerships and collaborations as well as my own judgement on their willingness to participate in an open innovation strategy.

I have only shown the backgrounds of the 3DCP companies. For the BIM and the construction ecosystem players, there was a much more varied background, as you would expect, with the obvious exception of the software providers who all have IT backgrounds.

5.7.4 Vision

I'm really, really passionate about enabling the construction industry that we serve. Enabling the level of disruption *I010_SoftAlpha*

What struck me from the interviews was the level of passion and commitment to change from the new ventures. Contrasted to the weariness and cynicism that was the general mood from many of the incumbents. The smaller firms interviewed all had the biggest ideas on how they wanted to change the industry. It was rarely just about the printer or the software, it was about the bigger picture.

My biggest passion is development in a broader sense of word, of the word. So that means personal development, development in the team…as well technical development *I015_3DBeta*

These firms perhaps had a more youthful management demographic than the incumbent firms which would partly explain their enthusiasm but generally they are also led by CEO's who all had an entrepreneurial or maverick outlook (Even the ones who had a construction industry background). These senior executives were of similar age and work experience to the incumbent construction firm executives, all be it in different industries. But I was struck by their vision and clarity of purpose.

We want to build and develop the machine and the software and the ecosystem around it *I017_3DAlpha*

I want to change the way we develop land and communities, not just build houses. Because I'm really looking at this is to be the most customer-friendly construction entity out there. *I020_3DZeta*

We intend to build 500,000 homes in a very short period of time.
I032_SovFund

This begs the question of who in an incumbent firm or new venture leads the innovation within it? If incumbents are too large to replicate the youthful ambition of the start-ups, they need to at least try to nurture an innovative culture amongst their employees. McKinsey believe that an innovation culture needs to be embedded into an organisation through key personnel or a mission statement (MGI, 2017:102). A recent study highlighted a growing trend of large companies towards appointing a Chief Innovation Officer (CINO) to the board. As of 2017, only 29% of companies in the Fortune 500 have a dedicated innovation specialist in the senior management team (Lovric & Schneider, 2019). They list six different types of CINO's based on their personality attributes with a wide range of skills, whilst many firms suggest that a CTO (technology) or CMO (Marketing) person can fulfil this role alongside their other responsibilities, but neither approach is really satisfactory in my mind. Innovation happens across all divisions, be they technology, marketing, sales or operations. As shown above, it is not one particular product that shows a company to be innovative, it is also the business model and internal processes. Smaller ventures utilise their small executive team as a collective innovation think tank, but for incumbents to survive and thrive they need to specifically appoint someone for this role, who reports into the Board or CEO. This person is in charge of a small team with diverse skillsets to target innovation across all divisions. This small team can break down the barriers to innovation through behaviour enablers, artefacts and nudges (Anthony *et al.*, 2019)

with techniques to get the whole organisation focused on change. This will help alleviate silo thinking that is common in a conservative sector and allow a wider outlook on the direction of the firm both internally and externally:

To say this industry is going to be defined by a particular product in 5 years' time is probably less helpful in your journey towards building an innovative organisation. The nature of the world around you at the moment is that you might set off on that direction there. But someone's going to disrupt you, someone's going to come in completely tangentially and take you somewhere else. If you've invested all of your capability and pushing towards that particular technology or product, you're going to be less able to be able to respond to the disruption that comes in from over here. I051_SoftGamma

Innovative companies employ a diverse multidisciplinary team to bring in experience from non-construction industries. It is easier for outsiders to take a fresh view of the status quo and to challenge it by adopting an outsider perspective and an disruptor mindset (WEF, 2017). But any team needs to have a method to channel the innovative thinkers and point all the horses in the same direction. As such the designated CINO should act as the orchestrator of the team, not as the generator of all new ideas. Research on behavioural economics points to group decisions shown to be superior to individual dictatorial ones especially those that engage in premortem to avoid biases and heuristics (Kahneman, 2011). Used alongside the nudge tactics seen in other industries as well as countries to alter employees to adopt better choices (Thaler & Sunstein, 2008), an innovative mindset across all employees can be instilled even for those of incumbent, conservative construction firms.

The 3DCP firms all had a clear view on the vision to improve but they also need to acknowledge that as small teams grow into larger ones, entrepreneurial companies have a tendency to become less innovative unless they can widen the culture and vision away from just the founders. So even for these small ventures, an early decision to formalise the innovative culture and decision making process across technologies, processes and business models is also a key element for success.

5.8 Ecosystem Strategy

5.8.1 Keystone Player

I don't think there are (in the construction industry). There isn't (a keystone), there are key players *I047_DoorsAlpha*

I think it's farfetched to think that we're the centre of the construction universe…it's such a wide area. *I004_SoftAlpha*

An ecosystem represents the *"alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialise"* (Adner, 2017) where groups of firms deal with non-generic unique or super modular complementarities, require the creation of a specific structure of relationships and alignment to create value (Jacobides *et al.*, 2018). Therefore the ecosystem can be deconstructed into a set of activities, actors, positions and links (Adner, 2017). Iansiti and Levien (2004a) describe how a central focal firm can act as a keystone player in an ecosystem. In contrast Calton *et al.* (2013) describe a decentralised network with interactive processes of co-creative learning, within a shared problem domain, which they label a "community of practice."

As the construction industry is such an enormous industrial sector, it perhaps is not a surprise to find that almost all the interviewees could not name a dominant keystone industry player across the whole sector. For BIM, as a top down mandate, it is the government departments that can be classified as a keystone player. They exhibit the characteristics required as they provide direction, capital, the incentives to join and the anticipated value from participation (Adner, 2012; Adner & Kapoor, 2010).

It's the government, ... they are trying to do it ... they're trying to work with as many states that are ready. It's a project from the centre, but they are working with private developers at different state levels *I006_AfriHouse*

This ties back to the industry suggestions on how governments can play the three key roles of smart regulator, long term strategic planner and innovative project owner (WEF, 2017). For BIM they are acting as all three. For the UK, the Construction by 2025 vision provides the long term strategic plan, the BIM levels provide the regulation and the establishment of Innovate UK can be seen as the conduit for innovation.

But the firms are affected in different ways by this top down approach to innovation and disruption. As with Moore (1996) different ecosystem layers are evident with incumbent firms reacting differently to the government directives compared to the new ventures, perhaps giving a glimpse of their mindset with regards the opportunities for innovation within their companies and their current ecosystems.

This became clear once they were asked to consider subsectors of the construction industry more key players were then mentioned. This perhaps reinforces the idea of nested ecosystems, with big fish in small ponds but no overall keystone in the larger

oceans. It also highlights how firms concentrate on their closest layer of ecosystem. These appear to resemble a more structured arrangement with the wider ecosystem layers viewed as an affiliation (Adner, 2017). Also interesting was that even though DoorsAlpha is one of the top three companies in the UK and SoftAlpha's client list includes over 70% of the top construction companies, and WoodAlpha is one of the UK's largest timber frame suppliers, none of them immediately saw themselves as a keystone player. However, once they were asked about a specific product or process area, then they admitted being a large player and influencer.

We are pretty key to a fair chunk of the UK construction. *I004_SoftAlpha*

And all the technical work around it really, the timber frame centralises and clusters around ourselves. *I014_WoodAlpha*

I don't think our brand is big enough and our differentiation isn't great enough, to what they are now We'd like to be. *I047_DoorsAlpha*

What was interesting was that none saw themselves as irreplaceable. The size of the industry and the emphasis on price meant that they all believed that competitors would easily replace them. For the software companies they thought it more likely to be acquired as replacing the software used by companies is more complicated and would take longer than replacing a hardware supplier. The hardware suppliers and builders saw the multitude of competitors likely to just wipe them out and take their market share.

For the 3DCP companies, the executives definitely did see a small number of key players or potential keystones in this emergent industry.

Currently, yes, I would say 3DBeta, 3DRho, and our company (are) the three most interesting *I017_3DAlpha*

Perhaps this is due to the relatively small number of firms currently offering 3D construction services and the current lack of demonstration prototypes and projects. This may change as second movers move in now that the concept has been proved. Especially as the number of companies offering 3DCP has risen exponentially over the past few years from 20 in 2013 to 65 by 2018 (Laubier *et al.*, 2018)

In relation to D'Aveni's theory that manufacturing titans will emerge, this was not apparent yet. When pushed on who could be a keystone, it was the IT and CAD

providers that were mentioned most often. Microsoft has moved into construction as a provider of Cloud computing services whilst AutoDesk was named as the largest provider of CAD design software. Both were seen as complementarities providing important components to BIM innovation.

Microsoft are absolutely key starting point for the ecosystem. When you move beyond the providers of the raw technology, then obviously they're a significant part of your ecosystem…Business partners that you need to provide the complementary technologies that are required to deliver your type of solution to the market

I010_SoftAlpha

Autodesk which are always like, a dominant supplier in the industry. So, they're almost there on that really *I014_WoodAlpha*

Platform Leaders should look to establish a product platform rather than an individual project perspective adopting the practice of product platforms seen in the automotive and other manufacturing industries (WEF, 2017). Interestingly both Microsoft and Autodesk provide free software to schools and universities, to get people used to their technologies at an early age. Familiarity could be a key influence. The other CAD companies observed in this research are using open source software and open innovation to expand their products. All are moving ahead with 3D CAD technologies which could disrupt Autodesk's current dominance. The 3DCP companies all expressed issues with the Autodesk suite of software tools and were actively using newer start-up companies to develop their proprietary slicing and tessellation algorithms, which suggests it is not assured that Autodesk will become a keystone platform leader.

I think AutoDesk tries to be, but they are not taking the right steps, or maybe just not fast enough. I think that they try to be the market leader in such a way that they are more of a monopoly *I017_3DAlpha*

An area for future research could focus on Autodesk versus the CAD/CAM disruptors within construction over the next few years as BIM reaches mainstream adoption. Many of the interviewees saw Autodesk's high licencing costs as a large barrier to more widespread adoption of CAD technology amongst SME builders.

An open BIM compliant computer aided design platform that Joe Bloggs builder could log into to knowing that there's a knowledge base of information in there that would enable him to accurately create a model of whatever it was that he wants to build…I think that would be a real innovation in terms of the mass construction market because the trouble with the CAD technologies has always been historically unbelievably expensive *I010_SoftAlpha*

In summary it is inconclusive that a keystone player will emerge as a manufacturing titan (D'Aveni, 2018) for the construction industry. The enormous size of the sector requires substantial investments and resources. This is not to say it cannot be disrupted as Airbnb and Uber are currently trying in other sectors, or that a platform is not in the process of being constructed, just as Apple waited to have all the complementarities before launching iTunes. Typically, it seems the size of the ecosystem may determine the speed and influence for a keystone to emerge.

5.8.2 Stakeholders and Partners

The technology… this emerging industry that we are speaking about needs more resources to develop faster. We need cooperation with academia, …also leading corporations to the conventional suppliers, the materials suppliers and normal technology suppliers, the leasing guys, the construction companies, we all need to get involved *I049_3DAlpha*

When choosing partners, the new ventures face the same stages described by Moore (2006) in that whilst they may want to be selective, at the beginning that may not always be possible. For the incumbents viewing the adoption of BIM or new technology, they have pre-existing partners and suppliers of key components for their needs. The 3DCP new ventures do not have that luxury. They face the traditional issues in being under-resourced and underfunded when compared to their aspirations. What was interesting is that a lot of them had used research institutes and research grants to help them through the first development stages. A knowledge ecosystem was their main route to establishing their innovation and to help them market their product to the small early adopter community through the universities network of company links.

We have a large international and national network of interests in construction. We actually have two universities close who have been working with this. We have very

soon 3 universities, so they are taking research from the universities and helping companies actually use it out there in the commercial world. *I017_3DAlpha*

Of those companies analysed a majority of the more current leaders, defined as having built a proof of concept building and already working on large commercial demonstration projects, had links to a research university. This knowledge ecosystem is the starting block of the company and helps them link into the 3DCP community through seminars, research projects and white papers.
Once they have achieved this, then they have branched out to a wider ecosystem involving construction companies and governments as well as financiers to build a bigger innovation ecosystem and develop a business case. It is this stage that most of the pioneer 3DCP companies are currently at. At this time, it is no longer explaining the technology to get a foot in the door it is more about understanding the customers' requirements:

It was not about selling the printers, but more like understanding the problems of your potential partners *I015_3DBeta*

For the wider ecosystem players, they are viewing the technology with interest but are currently not engaging in strategic collaborations. They are still in the pilot testing stage even for larger scale developments. Again, the issue of capability to execute is paramount and the smaller new ventures still need to prove themselves:

We have 127 developers. We are signing up large scale developments with large scale developers with experience and track record for executing large scale development…the second challenge is the continuous engagement route, which is basically one off relationships with small to medium size development companies
I032_SovFund

As the technology develops and moves from concept adoption to early adoption phase (D'Aveni, 2018) which some of the more successful ventures are already reaching, then they are now choosing which projects to spend time and effort on and which partners to collaborate with:

I think that the golden rule…something in it for both partners, but there's something that's different. One might be creating the market, the other might be creating technology *I013_UniAlpha*

For the BIM software developers, they see the need to bring in various skillsets to complement one another. As the construction plan of works consists of 8 stages (RIBA, 2020), no one company so far has a platform across all of them. This means they have to work with leaders in other areas to advance their offering:

Digital twins, we bring several disciplines together, we have disparate models, we've got architects, we've got architectural model, we've got structural engineers, we've got structural model, mechanical, electrical plumbing, services that actually make the building tick, and these all come together. *I048_SoftBeta*

So, there seems to be a progression from a start-up with its *knowledge ecosystem*, which branches out into a wider *innovation ecosystem* and then develops into a *business ecosystem* as it becomes ready for commercialisation. Incumbent firms are already at the business ecosystem stage. With BIM coming in and disrupting their status quo, they are beginning to become more open and collaborative as they start to see a bigger picture. This is the tipping point into platforms developing over the next few years and titans of construction emerging, if D'Aveni (2018) is right. It is at this stage that some of them will choose to be platform ecosystem leaders or just followers in the new emerging ecosystem (Adner, 2012).

5.8.3 Ecosystem Collaboration

I think cooperation and collaboration partnerships is an opportunity at every stage in a business, but it then depends on whether your business and your competitors, are suited to that type of behaviour *I012_3DPAM*

The residential solar industry has been researched from various ecosystem perspectives (Hannah & Eisenhardt, 2017; Kapoor & Furr, 2015; Overholm, 2015). As this was a nascent industry, the formation of the ecosystems and the competition and collaboration as well as the complementarities required serve as a useful comparison to the 3DCP and 3DP research here. The solar service industry is analogous to the 3DCP companies which may also be unable to create protectable assets through intellectual property protection but need instead to rely on a specialised business ecosystem where they can innovate amongst themselves and share the rewards through a dramatically enlarged market.

We are collaborating So we are developing technology and they are actually in the process of spreading it out…We tried to make these collaborations with many different companies in the industry. *I017_3DAlpha*

Digital twin is more of a collaborative processing of people working together…This is the vision. This is the ethos *I048_SoftBeta*

The process of creating their ecosystem came organically for many, rather than a fixed business plan. The idea to enter the market was led by a passion to change construction and utilise new technology after seeing its potential benefits rather than an initial ecosystem strategy. Whilst this market is so new, it remains to be seen who will emerge triumphant between the first movers and the fast second movers but the ecosystem strategy literature on bottlenecks at the start of ecosystem genesis is highly relevant (Hannah & Eisenhardt, 2017), with financing partnerships at the initial stage something the small new ventures need to develop. However at this nascent stage the 3DCP companies appear to have followed the limited business model strategy of other pioneer firms in the solar industry due to resource constraints rather than be able to pick and choose their likely final counterparties and partners (Overholm, 2015). This sounded familiar to the CEO of 3DPAM:

There were opportunities for us to cooperate to develop the market, and they weren't taken…Why didn't they cooperate? Probably because they were in the stronger position. They had multi-million government funding. We had nothing. So, we just had to scrap along and try and cooperate with whoever would talk to us to start with. whereas they didn't need to cooperate because they had the funding and the financial strength to just go from the outset. *I012_3DPAM*

The 3DCP ventures recognise a need to embrace all potential projects that advance the technology and get the marketing message out there to establish the solid base to move forward. Obviously, they must still be cognisant of choosing the right collaborations. The BIM companies were only too aware of wasted time if you cannot find like-minded firms:

We are being very collaborative doing that way. The risk of course is, is make sure you don't pick somebody who is too inward looking. Or backward looking.

I002_SoftAlpha

Followers entering this market may be able to bypass some of these initial stage issues but if the technology reached mainstream adoption then the enormous size of the construction sector presents an opportunity for pioneers to accept that whilst they have to initially be prepared to bear all the costs to assemble the ecosystem players, they will eventually capture the largest value rewards (Adner, 2012; Teece, 2007). Cost has been mentioned numerous times as a barrier to adoption, so rental and lease plans are being actively pursued by 3DAlpha, through a strategic partnership with a much larger, well capitalised construction industry hardware supplier, who already have a working rental business strategy. This allows 3DAlpha to focus on technical development of the innovation whilst utilising their partner's capabilities in the marketing and financing of their machinery. This is in contrast to most of the other 3DCP companies, including 3DBeta and 3DZeta, who at this stage are still focused on selling printers or providing a full service construction and project management service to raise the capital required to grow their business. From the experiences in the residential solar industry, they would do well to follow 3DAlpha's approach through a bottleneck strategy rather than a component or system strategy (Hannah & Eisenhardt, 2017).

What is also clear from many of the interviews is that there is a pragmatic approach to which technologies will be the most successful. Whilst there are four different technologies listed for 3DCP approach (Table 5.1 above), they all recognise that there is room in such a large industry for all of them. Whether robotic arm or a gantry extrusion system will be more appropriate is dependent on a variety of factors. The 3DCP community shares ideas and knowledge across the value proposition of automated construction rather than a particular machine or technique.

We actually see that these technologies are missing, there's not one clear way of doing it. There are multiple ways that this can be combined. They have specific advantages and disadvantages. Could it be that some of these technologies are particularly useful in certain projects? And then some of the technologies are particularly good for other projects. So, in other words that we don't talk about one size fits all here. We talk about different technological solutions to different type of buildings. I think this is the way forward. *I049_3DAlpha*

As the technology develops this pragmatic yet open innovation approach will allow the companies to remain flexible and incorporate all types of innovation from technology (modular, gantry, offsite vs onsite, materials, etc.) as well as processes such as BIM and business model innovations such as rental plans.

I think within every project, depending on the design, the process, the people that are involved, another construction methodology is most beneficial. And there were a lot of factors, I've learnt through the last couple of years that are influencing whether a kind of construction methodology is interesting or not. *I015_3DBeta*

As Overholm (2015) states '*as entrepreneurs initiate ecosystems through strategic actions, they also create opportunities for other entrepreneurs'* . At this stage of development, it is too early to tell what the most successful strategy will be although there are some clear commonalities in several areas – training, proof of concept, hype, research partner even before addressing the need for strategic partners and eventual platform winners. In effect all the 3DCP are pioneers, even those that have yet to print a house. Their ecosystems are still being iterated and changed as the technology progresses and new adopters are discovered. Social changes and economic changes will probably play a major part going forward but at this stage it is too early to say what the eventual marketplace and winners will look like. As such disruptors need to keep an open mind to possibilities and continue to break down traditional industry barriers.
MX3D when seeking a collaborative set of partners for its Bridge project, attracted key industry participants by committing to advance the technology through shared accumulated knowledge. By collaboration, they built up trust amongst the partners who have continued to be involved in subsequent projects. These partners duly contributed their complementary competencies to the venture and have continued to do so beyond the project (WEF, 2017). This leads to an adjacent factor for collaboration, the degree of openness in the ecosystem.

5.8.4 Open vs Closed Innovation

I think our approach has been very open until now, because we have learned a lot from the …other companies and universities. And we have somewhat tried to share that as much as possible. *I007_3DAlpha*

The pooling of knowledge for innovative purposes (Chesbrough & Appleyard, 2007) can lead to greater strides being made in the development of a new innovation. Without this companies individually all look to solve the same problem, and all expend time, effort and resources on problems that might be more efficiently solved by collaborating with trusted partners as in the MX3D Bridge project mentioned above. It appears that the 3DCP companies are being open in sharing their technology and test results with a wider audience, both potential competitors as well as customers and complementors.

We have this, like, a learning community. We share all the new things. Based on that, this gets better and better. We're open, but within our own community.

I015_3DBeta

Recent literature has researched how incumbents moving to an ecosystem or open innovation business model need to find strategies to transition and find management teams that embrace this ethos (Altman & Tushman, 2017). Senior executives in traditional industries, like construction, struggle as they try to convince various divisions to move to a more open collaborative strategy. Evidence from other industries that have traditionally favoured internal excellence and capabilities find challenges to convert the culture to one of openness and external collaboration, but the message seems to be getting through:

One thing that will stand out is two alleged competitors opening up and collaborating and sharing information…because they saw the advantages of what they could do with this *I050_ConConsult*

For the incumbents looking at BIM, they can see the benefits if the vision comes through, but most appeared cynical to how quickly and how far an open innovation culture could permeate the construction industry. However, the requirements to adopt BIM or risk being part of a large government sponsored construction project seems to be having the desired effect. It is also driven by the need to reduce prices in an industry that is typically only operating on a 2-3% profit margin.

It's getting there but the danger is we're all trying to innovate ourselves, when we should be doing more open construction. *I018_WoodBeta*

As the amount of practitioner literature as well as the academic literature becomes more widely circulated then the collaborative, open innovation strategy becomes more established. The emphasis on circular economy and sustainability will be a key driver alongside the reduction in costs and time (Tay *et al.*, 2017). And within the changing dynamic capabilities and skillsets of the workforce as low skilled labourers are replaced by graduates with IT, robotic and automation backgrounds, as seen by many of the participants in this study, the crossing of traditional boundaries can lead to openness and co-opetition (Altman & Tushman, 2017).

I think historically we've been closed, but I think that has been changing. So, I think what we've recognized is we don't have to do everything in-house I002_SoftAlpha

In a rebuttal to Adner (2017) who believes that ecosystems see external multilateral co-ordination whilst open innovation is an internal process, this was not seen in the interviews here. The 3DCP executives have deliberately embarked on forming a collaborative community to solve problems and share solutions with their ecosystem partners.

Three really simple steps to be able to build that innovative organisation, that organisation that can face that disruption that is going to happen every day.
The first thing you need to think about is modernizing…(secondly) I am less interested in the amount of stuff that you build; I am more interested in the amount of stuff that you throw away. Because unless you are throwing lots of stuff away, you are not moving fast enough…(thirdly) the culture that you build inside your organisation. And that is an innovative culture that exists everywhere…The inclusiveness of your innovation and culture will also help you navigate those difficult moments.

I051_SoftGamma

5.8.5 Trade Body

Trade body of 3D concrete printing it is way too early. We don't even have a like a branch organisation…There's definitely discussions across the companies and the…But there's no like single body that starts to discuss all of these things…So we don't have a common language. So, like the same thing can be called like four different things in different companies at different universities. I017_3DAlpha

Successful innovators also need to engage with regulators to set new standards for an emerging technology such as 3DCP they are seeking to shape the regulatory environment, working closely with construction departments and regulators at a state and national level (WEF, 2017). The experience seen in the timber frame housebuilders in the 1980's points to a requirement to have a structure that can act as a discussion forum for those involved in a new technology or industry. A new technology attracts many participants yet unless there is a certain level of training and competence, then one or two bad apples can rot the whole barrel. This as described above, set the timber frame sector back and has taken 30 years to claw back yet still only represents 28% of the housebuilding today.

The early 80's and then there was some bad publicity because … the new technology and it was Barrett's at the time who hadn't constructed the product right, but it was nothing to do with the timber frame but the industry because of this Barrett quality issue got trashed. *I014_WoodAlpha*

The problem is that whilst new ventures are busy developing their own technology and refining their innovations, there is not the bandwidth to lead a forum without a strong set of initial players. For the 3DCP companies, they have been successful in that one or two highly driven leaders have forged a strong community across the start-ups. But it still appears too early to have a formal trade body to represent them:

So, there's no industry, there's no organised efforts toward this. There's a lot of different players who want different things and so on. So, but I believe it will come and how fast, it's really a matter of who is pushing forward. *I017_3DAlpha*

But the players in this tight ecosystem need to follow the example of the timber frame companies and form an industry association as soon as practicable. Industry trade bodies and regulators help define new standards and can assist in providing financial resources improve the amount of risk borne by an individual firm. They can provide the grants and subsidies by co-investing on proof of concept projects (MGI, 2017). This will give innovative firms more control over the development, the standards, the definition and the reduction of overlapping research to turbo drive the sector.

I was chairman of that industry association for a couple of years… I ended up managing the industry through that…it actually has clout and it has quality control…it made me get the industry some teeth to it…So we're an expert in our field.

I014_WoodAlpha

It is not just technical issues relating to the machinery or software that needs collaborative thinking. Standard contracting and procurement processes are cumbersome and inefficient. Most contracts are won through an auction process usually won by the lowest bidder, regardless of longer term cost and performance with the majority of projects coming in over budget and rarely on time. So, regulators, trade associations and project leaders must be engaged at the outset, to make the process more efficient, cost effective and sustainable. 3XMD's Bridge project sought early engagement with the city planners to create a collaborative and trusting relationship of

co-ownership of the project to advance the technology (WEF, 2017). If a collection of companies can collaborate at this early stage, then the collective power of the group is far stronger than just the sum of their individual parts. If they can trust each other, then all participants can capture value as the industry size as a whole grows.

We used to be in a situation where nobody collaborated…people went down different routes trying to get to the same aim. We then started creating technical committees…and they'd come up with solutions and we then bring it back through the commercial people. *I018_WoodBeta*

Studies in behavioural economics point to collective power as superior to individuals in making judgements and has been proved especially effective with the elimination of hindsight bias and other heuristics by the use of premortem strategies (Kahneman, 2011). In a premortem, as opposed to a post-mortem, board members read and deliberate the board papers and give their opinion in writing before the board meeting. This eliminates the opportunity to change their mind and subserviently agree to a forceful chairman or CEO in the meeting and then in hindsight say that their initial thoughts agreed with the CEO. It has been shown to be more effective at eliminating poor decisions on company strategy. However, in an ecosystem context, there must be a high level of trust amongst the senior executives or the old issue of compete versus collaborate is always a fine balancing act.

As expected, the interviews with the incumbent software and construction senior executives pointed much more towards competition and closed innovation. Even though some of them mentioned a recent trend towards collaboration, they still saw and exhibited a reticence towards open innovation and collaboration.

Open vs. closed systems, because a lot of it's down to fear or lack of imagination. Now maybe I'm a little bit hard-nosed on this one…by being perhaps a little scathing by suggesting its lack of imagination. *I012_3DPAM*

This alludes to the fact they are more established companies and act more like Stage 3 Leadership, incumbents on Moore's definition (Moore, 1993). The top down mandated move towards BIM again seems to point in a different direction to the bottom up direction on collaboration for 3DCP.

5.8.6 Ecosystem Strategy

You need all those ingredients for it to work. And the challenge is, whenever one of them isn't in place, it's difficult to make it a success. For us it's refreshing, because what they're doing is, they're saying, "I can see you've got these various components that we haven't been able to join up" *I002_SoftAlpha*

All the component parts of the ecosystem, as described in the sections above, have to be managed by the focal firm through a strategy. Adner (2017) defines ecosystem strategy as the *"way in which a focal firm approaches the alignment of partners and secures its role in a competitive ecosystem."* It is an iterative ongoing process depending on the players and complementary components required and involves risks as interdependencies and capabilities are formed (Adner, 2012; Zahra & Nambisan, 2012). A firm's choice of ecosystem strategy depends on how many ecosystem components they produce, which complementors they wish to align with and the balance between cooperation and competition (Hannah & Eisenhardt, 2017). The strategy will also depend on whether a keystone player (Iansiti & Levien, 2004a) is present to lead the ecosystem, as can be seen as the government's role in BIM, acting as a central stakeholder (Freeman, 1984) or a decentred network (Calton *et al.*, 2013) as currently is seen in the housebuilding process in the construction industry (a series of keystones within their individual ecosystems who have a link into another ecosystem or value proposition). Overall as firms assess the ecosystems activities, actors, positions and links, at its heart ecosystem strategy is the search for alignment (Adner, 2017) .

For 3DCP the activity is currently aligned around a knowledge ecosystem with a specific value proposition to develop the 3DCP technology with the technology at the birth stage of ecosystem development (Moore, 1993), although the pioneer firms are beginning to move from the concept to early adoption phase.

There's a lot of cooperation between academia and business…it's a really good way to push a new technology forward as well *I017_3DAlpha*

As they grow and have proved their technology through a proof of concept, the emphasis is changing from just being part of research community and research grant led projects towards larger scale innovation ecosystems where more partners are added to the ecosystem to bring in their skills and knowledge and move from concept to early adoption phase (D'Aveni, 2018).

And now we're doing another one, together with I think 14 other companies, it's really big…we were just seeking the investment at the fund. And then we partner up with a construction…and some material companies, to know about materials.

I007_3DAlpha

Therefore the research suggests a progression across different types of ecosystem, from knowledge to innovation to business ecosystem when a new innovation starts from the bottom or low end, grown organically to try and disrupt the incumbents (Christensen & Raynor, 2003). Little research has been conducted into this area yet with the exception of Clarysse *et al.* (2014). However, I do not find that these knowledge ecosystems centre around the research university as the keystone player. In effect they are just the conduit for the innovative firms to meet like-minded firms and build a community, but the university is not the visionary that is looking to build a business and commercialise the products. It is more a collaborative group with no discernible leader but with all ecosystem actors playing their role in a more structured approach to generate new knowledge. However, the universities and research bodies can act as the conduit for the government in the role as a grant funded incubator to help these new ventures to raise capital at the early stages, although the experiences of many in the UK point to a bias towards larger companies still receiving the majority of funds, which in my view acts as a barrier to innovation.

For BIM it is an existing business ecosystem for the wider construction sector that is being disrupted by a government mandate. It is a much bigger overall ecosystem with the keystone player being the government initially but now that the directive to adopt BIM levels have been issued, the keystone players can emerge at the next ecosystem layer down at the industry level. Again, no discernible clear leaders have yet emerged, but many firms are starting to decide their strategy. This type of disruption of the business ecosystem sees all incumbents forced to adopt the new innovation and disruption but to varying impacts. Therefore it more resembles an ecosystem by affiliation (Adner, 2017) with each incumbent now choosing whether to dive deep into the new technologies as a potential leader or to wait and see how it develops whilst trying to eke out the last value from their existing technology (Adner & Kapoor, 2016a). The value proposition applies differently to this myriad of actors.

Therefore, the strategies that are being deployed are different for the new ventures and the incumbents as they consider the structural components of their ecosystem as well as the type of ecosystem they are currently in and their vision for the effects of future disruption.

We have the right stakeholders in the industry to help shape it. So, you could argue that they use us as the vehicle for doing that *I002_SoftAlpha*

How the firms choose to build or reinvent their ecosystem therefore depends on an initial analysis of where they see themselves in terms of ecosystem maturity and willingness to embrace disruptive innovation. Once they have decided on that, they can decide how to build their ecosystem strategy.

However, a further consideration, builds on the research that highlights how *"even with the same set of actors in the same industry, alternative value propositions can give rise to different ecosystems"* (Adner, 2017). I also consider that firms need to identify which layer of ecosystem they are in, as a single firm can occupy multiple positions in multiple ecosystems, with different strategies applicable to them. This brings back to the concept of nested ecosystems within an overall ecosystem (Moore, 1996), with links to the different ecosystems either directly or indirectly through up to six degrees of separation (Barabasi, 2014) or through complex network and ecological analogies (Boccaletti *et al.*, 2006; Fontaine *et al.*, 2011). In effect being part of multiple ecosystems does not limit the ability of smaller players to operate in a smaller initial community driven by a value proposition as they still touch those in a wider environment, just as all creatures in a natural ecosystem can feel the warmth of the sun even if they are concentrating on their own activity.

In the Outcomes section, I pull together the various findings and incorporate them into a framework to allow companies to decide their position in the disruptive innovation versus ecosystem matrix and the subsequent tools they can use to create an ecosystem to capture value from a disruptive innovation.

6 Outcomes

6.1 Introduction

The stated aim of this research study was to consider how new ventures can create an ecosystem to capture value from their use of a disruptive innovation, and to provide a contribution to both knowledge and practice.

As my contribution to practice, using the themes that emerged from the data described above in the Findings & Discussion chapter, I propose a simple six step toolkit for practitioners in both new ventures and incumbent firms. This toolkit is based on my research into the construction industry but can also serve any industry being impacted by technological change.

My contribution to knowledge reflects the synthesis of existing research, both academic and practitioner focused, into a unified approach to thinking about the types of ecosystem and the types of innovation, when they are useful and how businesses progress through different ecosystems as they reach different stages of development.

I believe that these contributions are important at this crucial juncture for the construction industry, to help it adapt to new technology in order to overcome the industry's productivity problems, whilst also providing a direction to help solve the looming infrastructure and housing issues the world will face in the next 20 years due to world population growth forecast.

6.2 Contribution to Practice

It is one thing to observe companies that are involved in developing innovative technology and processes, but there needs to be a practical toolkit for them to build their business and reach a wider market with verifiable steps (1) to demonstrate the intention is to be disruptive or innovative (2) to showcase that innovation and (3) to understand the stages of progress that your company will go through. At all times during this research study I have tried to follow a thread - *Can I identify a disruptive innovation? - Is it an innovation of its time? - Does it need complementary business model innovation? - How do you build a proof of concept? - How do you build your ecosystem to bring the innovation to market?*

The following toolkit is based on the compilation of all relevant prior research found through the extensive analysis of existing literature, as well as the data collected for this study. Whilst there was little research into new innovations in construction, from a social science lens, there have been many research studies into disruptive innovations in similar as well as disparate sectors. Gaps in the previous research and questioning

of the underlying assumptions helped guide the toolkit into a practical contribution to existing knowledge.

Wherever possible I have followed the principle of Occam's Razor that a "*theory should rely on as few assumptions, and propose as few hypothetical entities, as possible*" (Lee & Lings, 2008:120). I remind readers that a DBA seeks the application of existing theories rather than to propose something completely new. The key concepts and themes derived from the research data, as described in the Findings Chapter, provided the framework for the toolkit.

The observed findings directly link the toolkit back to existing knowledge, as presented in the Literature Review Chapter, by considering how the six major themes are applicable to my adaption of Freeman's (1984) enterprise strategy. I have considered how these six themes synthesise against the components of his strategy along the three main areas for analysis (see Figure 6.1 below).

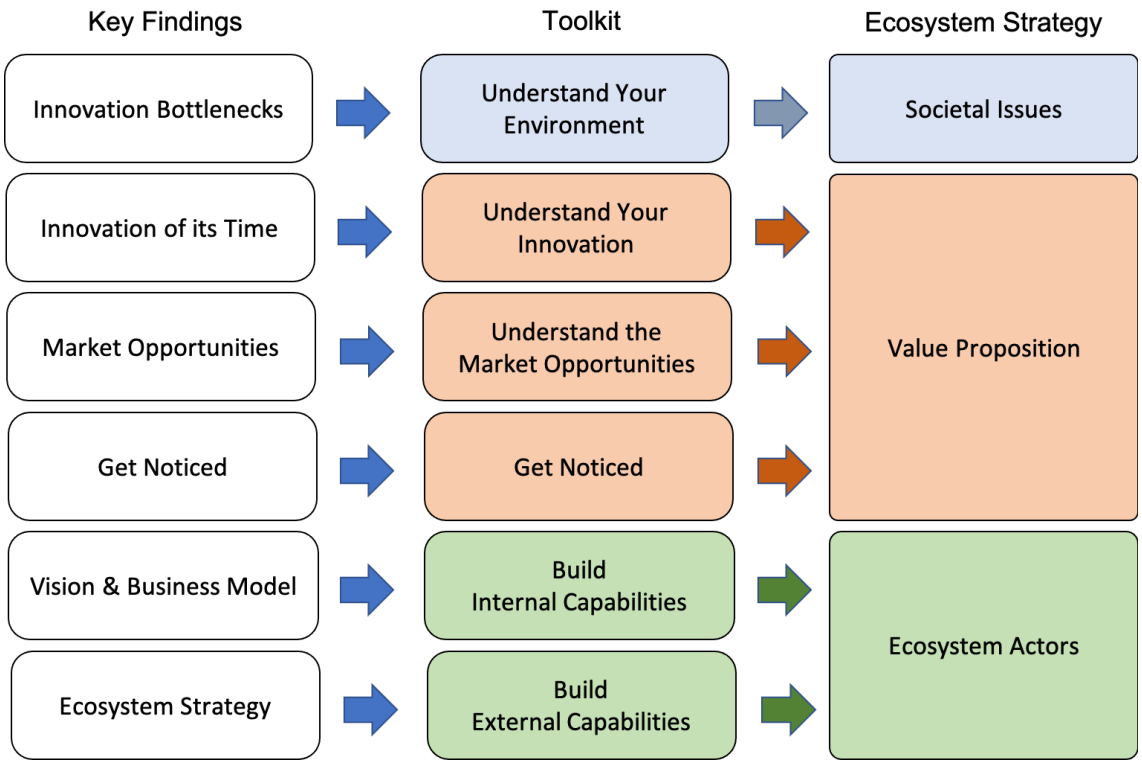


Figure 6.1 From Findings to Toolkit

I have incorporated both academic and practitioner papers into this simple but practical toolkit. Industry research led by the World Economic Forum series of papers on *Shaping the Future of Construction* (WEF, 2016; WEF, 2017) and the UK Government's Construction 2025 (BIS, 2013) have moved the industry towards innovative thinking and my findings are consistent with many of their proposals. In the list of key transformation areas identified by the WEF (2016) I have focused on three

identified key areas; *(1) Adoption of new technologies, materials or tools* (a reflection of my review into disruptive innovation in construction); *(2) Industry Collaboration* (relevant for my analysis of ecosystems); and *(3) Business Models* (consistent with my findings on business model innovation).

I have found the subsequent WEF paper on innovators (WEF, 2017) intersects with the work of Christensen *et al.* (2019) and D'Aveni (2018) and many others I analysed in the literature review, whilst a very recent report from McKinsey uses disruption and ecosystem as the main themes for how the construction industry needs to change (MGI, 2020).

6.3 Feedback on the Findings and Toolkit

Following the data analysis, in order to verify that the research findings were consistent with the views of the interview participants, as well as to seek feedback and comments on the usefulness of the toolkit, I re-engaged with 20 interview participants to represent a large cross section of the different types of ecosystem player.

I provided them with a full copy of the Findings & Discussion Chapter as well as a PowerPoint presentation of the Toolkit detailed in section 6.5 below. This allowed for confirmation that individual quotes had been correctly interpreted and for a discussion on the toolkit as the manifestation of the output from the wider research group. Of those contacted, 10 provided feedback of which 5 were recorded/documented with illustrative quotes included in this section.

Separately I presented various aspects of the research findings at conferences including the DBA Conference at WBS (Dec 2019) and a virtual SMS panel (Sep 2020) to gather additional feedback, observations and critical reviews from a wider audience including practitioners, academics and fellow DBA candidates.

Overall the comments were positive or provided thoughts on how to improve the research but affirmed the need for both new ventures and incumbents to formulate a strategy to bring innovation into the construction industry.

Very interesting points throughout. Would it be ok if I share this internally? I believe many of us would get great value from reading it. *I017_3DAlpha*

I think the toolkit covers (innovation in construction) nicely. *I005_3DOmega*

Since our conversation last year, we have started to think about what we want to be and are considering our future vision and ecosystem. We have changed our strategy to incorporate innovation *I018_WoodBeta*

The overall toolkit provides six steps and several people initially commented that, for experienced businesspeople, some of this was not new but that it helped them to focus on exactly what their strategy is:

What the toolkit is doing is, in some ways, pretty obvious practical things, but it's a pathway. I see a lot of people say yeah, we've got a strategy. 'So, let's have a look at it.' Then there's a lot of backtracking…It's that detail of a step by step, of stating the bloody obvious, but doing it and they weren't doing it. *I047_DoorsAlpha*

I think your model is where industries will get to naturally when they have a structural problem within their industry that needs addressing, caused by external factors. You offer a strategic approach to an old problem in an old conservative industry.

I018_WoodBeta

This led to discussions about which parts of the toolkit were new or useful. The initial feedback was that the six steps are too general and represent only a very high level view.

There is always a new set of vocabulary for what can be standard ideas, that may have circulated for some time. The skill is not in creating new terms but sparking ideas and creating a structure to allow one to take an objective view of what one is doing wrong. For any senior person in a given industry I would expect them to understand their environment and to understand the available innovation. *I018_WoodBeta*

We all know about the general disruptive innovation, that all these new companies come into the market and disrupt all these big companies. So, the basics of disruptive innovation, but to be honest, it's neither here nor there to the man in the street.

I005_3DOmega

However, as shown in Figure 6.3 below, each step requires additional points to be considered. This is where participants started to understand that although they have an idea of the concepts of ecosystems, disruption and innovation, they have not thought deeply about what these actually mean in their strategy and how they view or measure

them. In general, and in agreement with Christensen *et al.* (2015) the use of these terms and concepts is now ubiquitous, but many companies only engage in a cursory discussion of them for their strategy, so they are often misapplied or misunderstood. Understanding the current environment was expected for senior executives, but delving deeper into their actual strategy uncovered weaknesses in understanding the type of ecosystem and innovation they were engaged in.

Consequently, the feedback asked for more detail than just six steps so that it can be personalised for a clearer picture on what strategies different types of players should adopt. Discussions focused on how the government has acted as a keystone for BIM because of their powerful position as the largest infrastructure customer in the construction sector but this had not yet appeared in sectors such as 3DCP or other modern construction methods such as modular housing.

Who should use it? Governments or industry bodies. If so, you should give options to help answer the questions. They should be doing this and thinking about how they use this toolkit to set up the ecosystem. A National Innovation System for construction. It works in other places like Dubai and Singapore, China even but can't work well in UK as too much bureaucracy. *I047_DoorsAlpha*

Yet others already see how the construction industry is finally embracing the opportunities that research into innovation and ecosystems potentially bring and how the focus and language used is filtering through to incumbents:

There is a three year project called Advanced Industrialised Methods of Construction of Homes [AIMCH] bringing together key industry players, academia and Government departments to achieve new digital design tools and thus innovate within standard housing models. In effect this is a manifestation of the overlap between innovation, entrepreneurial, platform and National Ecosystems. *I018_WoodBeta*

This toolkit allows different players to review different strategies depending on their answer to the six areas highlighted, starting with the key concepts that are beginning to circulate within the industry. Therefore, although there are only six toolkit steps, within those steps are a series of further questions to consider and these lead to even further questions as the toolkit steps presented here zooms in from 80,000 ft towards a closer sea level viewpoint.

Discussions then focused on the individual steps rather than the combined toolkit and here it was apparent that some of these are already being used or are at the forefront of company strategy. The recent issues arising from Covid-19 highlighted how disruption from the unexpected requires new approaches through business model innovation.

Sometimes as a business owner it is easy to get bogged down in the detail of running a business rather than looking for the next step in development. With the impact of Covid-19 it is even more important to look to supply chain efficiency and to address skills shortages. *I018_WoodBeta*

One curve ball which will impact new technology is the pandemic. It is causing the industry to protect its supply chain and production facility... If you simplify the construction process you lower the risk and ultimately profitability is protected.

I019_WoodGamma

This resonates with the toolkit steps to build both *Internal and External Capabilities*. The lockdown can be viewed as a top down ecosystem approach, where the government acts as a keystone player, forcing many to consider how they must adapt in this new ecosystem and reconfigure their existing business models. Also note that the issues of productivity and labour shortages are now becoming apparent to incumbents. The respondents acknowledged that this research had clearly identified these issues and that the toolkit attempts to address them.

We have of course also been battling this new situation (Covid-19)… Our current efforts are to help our customers through their first projects, so the travel restrictions have forced us to focus on digital training and we are working to make it much easier to remote control our machines on the sites just in case this continues.

I017_3DAlpha

Similarly, companies are now thinking about business model innovation to adapt to the new normal. As part of the *'Get Noticed'* step, training is recognised as a key requirement and is being actively pursued by many of the 3DCP companies as a means of continuing to pursue the market opportunity regardless of the additional bottleneck from the travel restrictions.

My research also found that cost was the construction industry's number one priority and feedback confirmed that to '*Understand the Market Opportunity*' the companies

need to provide a cost benefit. This step can help ventures to capture value if they can reduce the cost and provide a particular product in a niche area aimed at the non-consumer.

We are throwing a lot of resources…to have commercial products in this field soon. This alone could explode into a very nice business if we can push the cost as low as we expect, so your point about niche is definitely not lost. *I017_3DAlpha*

As a practical tool to encourage new technology take up, you may need further simplification and emphasis on the financial gains which is always a pull to change.
I019_WoodGamma

Type of Innovation was also discussed and here the incumbents are fighting back against new construction techniques by beginning to understand their own product innovation and how to adapt their business model to compete.

In my own particular industry…there is a desire for innovation and a means of delivering It within commercial constraints. Whilst we may not see 3D printing as the way forwards we have recently taken on a new range of products.
I018_WoodBeta

Regarding the *Vision and Business Model*, several people commented on the idea of a Chief Innovation Officer and that it should be led by the large house builders first, who represent the leading players in the housebuilding sector. Many other companies will follow their actions for company structure and business model.

Barrett's, Taylor Wimpey, Persimmon – They should all be appointing a Chief Innovation Officer. *I047_DoorsAlpha*

In summary participants would have liked to see more from this research and pondered on how it could be improved. Whilst they acknowledged the emphasis on a practical value for companies in the construction industry, the question was how to turn this into a commercial framework.

You are bordering on a full strategy presentation without it having a full strategy content by adding market and competitor analysis and external analysis. Therefore, is the toolkit a strategy and execution or a toolkit to execute a strategy?

I047_DoorsAlpha

Lastly, a disappointment was that the research did not include enough of the cultural differences between the players and environments observed. I see this as a valid addition to consider this point but within the specified word count, some of my research had to be left out.

The only thing I would say considering Africa, is the cultural implications, where does this fit in. Creating awareness is very important. *I005_3DOmega*

However, the overall comments were positive on the value that a simple toolkit could provide, as an initial way to focus companies on how to benefit from innovation in construction. As a result of the reactions and critiques of this research I am confident that this toolkit represents a useful contribution to practice.

6.4 Ecosystem Strategy

To create and capture value from a disruptive innovation, companies must decide which ecosystem strategy to pursue. All companies need to have an ecosystem strategy, as the overriding component of their toolkit, to answer questions for the three areas for analysis containing the toolkit steps. Using the top down approach favoured by Freeman's strategy diagram I can reconfigure Figure 6.1 above to tie back to his analysis as highlighted in Figure 6.2 below.

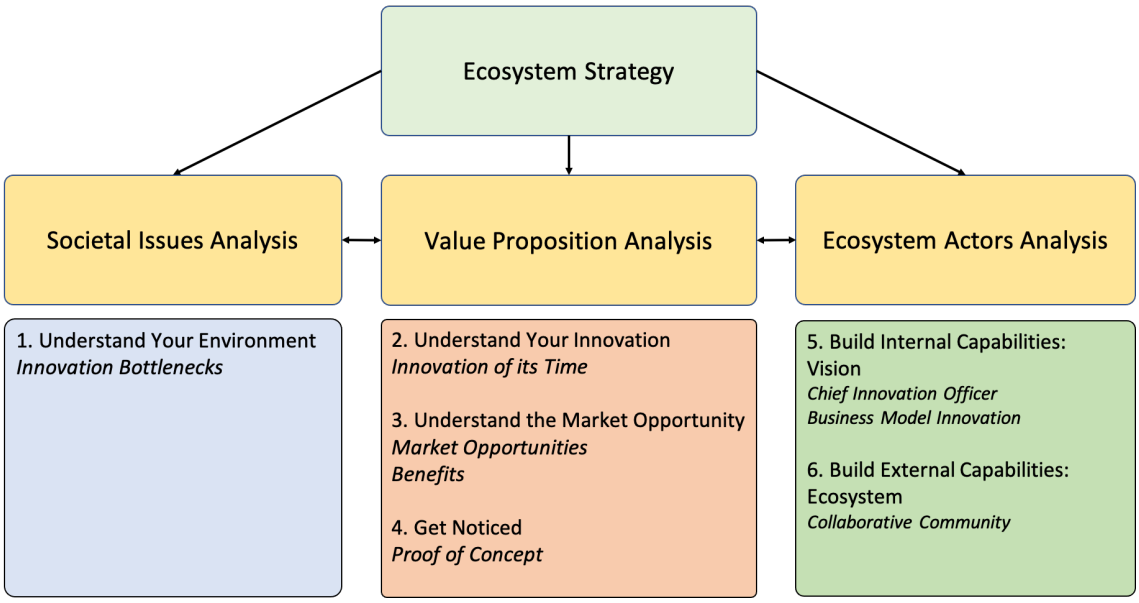


Figure 6.2 Ecosystem Strategy Toolkit (adapted from Freeman, 1984)

6.4.1 Societal Issues

Societal issues are growing in importance for companies to consider as part of their business model and strategy. As the construction industry is the largest contributor to waste and the largest user of many natural resources, the move to a circular economy will impact it the greatest. As a company develops through the various stages of growth and transitions into new types of ecosystem (*knowledge, innovation, business* or *platform*) they should consider how their innovation can address the larger societal issues and whether the ecosystem will be affected by the innovation in the near and medium term. Will you positively impact the world through your innovation? Companies need to understand the environment that they operate in and the bottlenecks that exist which prevents their innovation creating value in a sustainable and highly productive way. To understand your environment, companies need to understand their type of innovation, their type of ecosystem, their role in that ecosystem and the boundaries to it.

6.4.2 Value Proposition

Companies need to consider the value proposition for the ecosystem they are currently in. They need to think about what the shared values within the community are and what they are personally trying to achieve. They need to contemplate the benefits of a product or innovation for a (non-) consumer. Is it an innovation of its time? Will it provide a benefit over existing products and what is the market opportunity? If yes, then the key requirements to create and capture value are to showcase a proof of concept to grab people's attention and offer training to educate potential customers, stakeholders and consumers.

6.4.3 Ecosystem Actors

Once they have identified the industrial environment they will operate in, the market opportunity, and the value proposition their innovation brings to that sector, companies need to focus on their internal and external capabilities. For internal capabilities companies need to adopt an innovation culture and instil it throughout their enterprise. This can best be achieved by deliberately focusing on their vision and business innovation strategy. Next a company needs to consider the ecosystem that will most conducive to developing the proposition, what role they should play within that ecosystem and the governance, collaborations, and complementarities that will be required to drive progress.

Using the research findings to identify the type of innovation and ecosystem within the current environment (see 6.5.1 below), confirms the appropriate type of ecosystem for the next stage of company growth. Management can subsequently deliberate on the role they wish to play and decide on the most appropriate actors to invite in and interdependencies they have with or require from them. Companies need to build both internal and external capabilities based on their vision and use innovative business model strategies to develop or acquire them.

6.5 Toolkit

From the literature as well as the collected data analysed in this study, I propose six steps for companies to create an ecosystem to capture value from a disruptive technology or innovation and the relevant actions that need to be undertaken (Figure 6.3 below).

Figure 6.3 Toolkit Steps

To ensure a rigorous approach to this research Table 6.1 provides a brief comparison of crossover between the academic and practitioner literature with illustrative quotes

from the transcripts. Recall the five attributes that innovators and new ventures should consider when creating a new market with their innovation: (1) A business model that targets the non-consumers (2) an enabling technology (3) a new value network (4) an emergent strategy (5) executive support (Christensen *et al.*, 2019:29) and how the toolkit addresses each of them.

Table 6.1 Practitioner and Academic Literature Comparison

Toolkit Step	**Academic Literature**	**Industry Literature**	**Research Transcripts: Illustrative Quotes**
Understand your Environment	First Mover Risk (Teece, 1986) Bottlenecks (Adner & Kapoor, 2010) Standards (Teece, 2018b)	RIBA Plan of Work (RIBA, 2020) Future of Construction (WEF, 2016) The Next Normal in Construction (MGI, 2020)	*The construction sector, having worked in a few sectors, this is absolutely the least innovative of any sector* *CEO_I047_DoorsAlpha*
Understand your Innovation	An Enabling Technology (Christensen *et al.*, 2019) AM Scope & Scale (D'Aveni, 2018)	Adoption of new technologies (WEF, 2017)	*All the technologies are there it's just bringing the technologies together and so we can create something.* *CEO_I045_ConstructBeta*
Understand the Market Opportunity	Non-consumer targeted business model (Christensen *et al.*, 2019) The Wide Lens View (Adner, 2012)	Construction labour productivity could add $1.6 trillion value per year to the world's GDP (MGI, 2017) A $265 billion annual profit pool awaits disrupters (MGI, 2020)	*There is a lot of places where there are no houses at all. And this kind of technology will kind of build new techniques, new villages, new urban areas…when this takes off, it will be massive* *CMO_I005_3DOmega*
Get Noticed *Proof of Concept*	Concept Adoption Early Adoption (D'Aveni, 2018)	Develop pilot projects & proof of concepts (WEF, 2017)	*The proof of concept. Yeah, that's been most important, that we actually built a house…It's here, it's a physical thing. So, it's not just a promise anymore* *CTO_I017_3DAlpha*
Build Internal Capabilities: Vision *Chief Innovation Officer*	Executive Support (Christensen *et al.*, 2019)	Develop a vision and innovation culture (WEF, 2017)	*I want to change the way we develop land and communities, not just build houses. Because I'm really looking at this is to be the most customer-friendly construction entity out there.*

			CEO_I020_3DZeta
Build Internal Capabilities: Vision *Business Model Innovation*	Non-consumer targeted business model (Christensen *et al.*, 2019) The Wide Lens view (Adner, 2012)	Embrace business model innovation (WEF, 2017) To survive and thrive, incumbents must respond (MGI, 2020)	*The real practical barriers to innovation, is the mindset and the business model.* *CEO_I010_SoftAlpha*
Build External Capabilities: Ecosystem *Ecosystem Strategy*	An Emergent Strategy (Christensen *et al.*, 2019) Strong Industrial Platform (D'Aveni, 2018)	Nurture the broader Ecosystem (WEF, 2017)	*We want to build and develop the machine and the software and the ecosystem around it.* *CTO_I017_3DAlpha*
Build External Capabilities: Ecosystem *Collaborative Community*	A new Value Network (Christensen *et al.*, 2019) Co-Innovation Risk (Adner, 2012)	Industry Collaboration (WEF, 2017) The construction ecosystem of the future will be more standardised and integrated (MGI, 2020)	*We have this, like, a learning community. We share all the new things. Based on that, this gets better and better. We're open, but within our own community.* *CEO_I015_3DBeta*

6.5.1 Understand your Environment

To start from a solid base a company needs to understand the industry it wants to disrupt. Is it seen as visionary, fast moving and an early adopter of new technologies? Or is it a vast, fragmented and deeply conservative traditional industry? The company has to understand the barriers and bottlenecks it will encounter and the technical challenges, regulations and standards that will have to be met.

They will need to discover the level of collaboration that is likely to be forthcoming. This will be from the whole range of ecosystem players the firm will interact with and the interdependencies.

6.5.1.1 Review the Business Environment

All companies should consider the wider industry environment when developing their business strategy. They need to review the business environment they will operate in. They need to understand their type of innovation, their type of ecosystem, their role in that ecosystem and the boundaries to it.

Firms operate in a series of nested ecosystem layers with various degrees of structure or affiliation (See 3.8 Business Ecosystems above). They have a range of network connections of differing strengths to a variety of ecosystem players. Innovative

companies as part of small, heavily interdependent, geographically clustered knowledge ecosystem also need to review their affiliations with the wider industry ecosystems up to national level.

Companies should start by defining their current ecosystem at its most core level and how they are being affected by adjacent ones. Their position on an axis of ecosystem types and the expected progression of their business as part of a top down or bottom up approach will help form the initial basis for their strategy review (Figure 6.4 below)

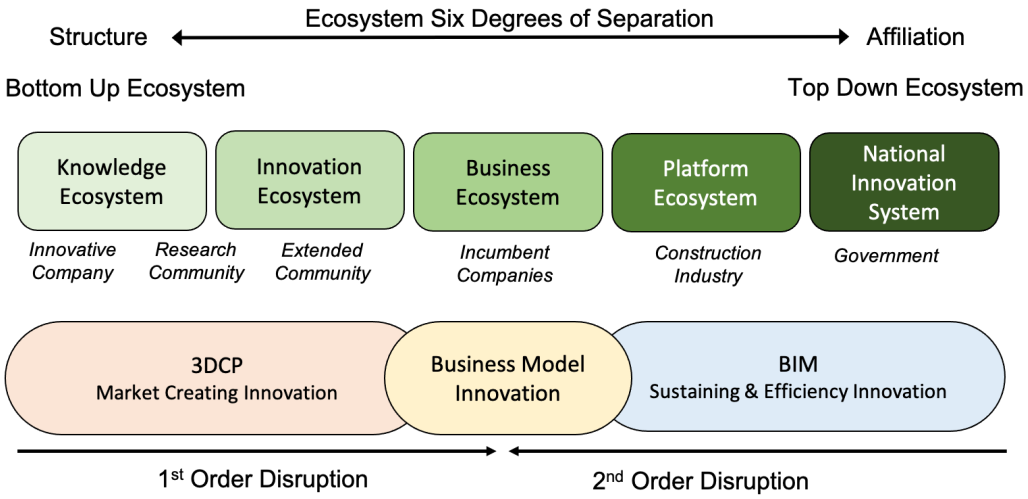


Figure 6.4 Ecosystem Environment

The various ecosystems and their definitions as described in Types of Business Ecosystem (3.8.5 above) can be summarised to aid the internal discussion on what a company can recognise and observe (See Figure 6.5 below).

Type of Ecosystem	Description
Knowledge Ecosystem	Primary goal is the generation of new knowledge. Typically companies are geographically clustered around a university or research institute. Acts as a connective concept between global business ecosystems (usually with a keystone) or a clustered geographical approach focused on stimulating regional economic performance
Frugal Ecosystem	*Low-End* or *Resource-Constrained* ecosystems reflect on the Base of the Pyramid research that observes how innovators can still have positive impact to provide high value at low cost for lower income communities. Typically requires a large group of actors focused on open collaborative business model.
Innovation Ecosystem	The collaborative effort of a diverse set of actors with a focus on innovation and technological development. Typically involves companies from different industries working together physically or virtually across the globe. Distinct from regional or national innovation ecosystems.
Entrepreneurial Ecosystem	Whilst sharing similarities with innovation ecosystems, the focus is on how entrepreneurial activity can raise the economic growth of a region through the creation of specific institutions and a culture. Typically involves regional policy makers working with entrepreneurs looking to innovate in all sectors.
Platform Ecosystem	Affiliated set of companies form around a 'hub and spoke' network where the platform provides a range of solutions for end users through a set of access points. They are a distinct form of ecosystem where network effects create value for both the platform and the users.
National Innovation System	NIS is a special form of ecosystem that revolves around systems at a national or country level. Similar to an entrepreneurial ecosystem, the focus is to be more innovative targeting economic growth and national industrial competitiveness

Figure 6.5 Summary of Types of Ecosystem

Using the structure or affiliation axis helps a company to decide both its current position, as well as the type of value proposition or innovation being considered, and how to grow the company and ecosystem to create and capture value from it.

If the company is a small new venture then it should focus on establishing itself as part of a knowledge or innovation ecosystem, in the first instance, to assist in the development of the technological or process innovation. The first aim is to demonstrate the innovation's benefits, so the knowledge ecosystem gives the venture a structure to collaborate on their ideas with others in the research community whilst also providing access to financing and business advice before they launch a commercial product. At this stage there are few real customers and only a concept. As early adopters take interest in the innovation, the ecosystem grows out of the research focused knowledge ecosystem into a broader innovation ecosystem, but this may or may not be a commercial value proposition yet. This is still a test and develop phase rather than a full-scale commercial endeavour. This is the proof of concept stage on a bigger scale and is where 3DCP currently sits as an innovation (See Figure 6.6).

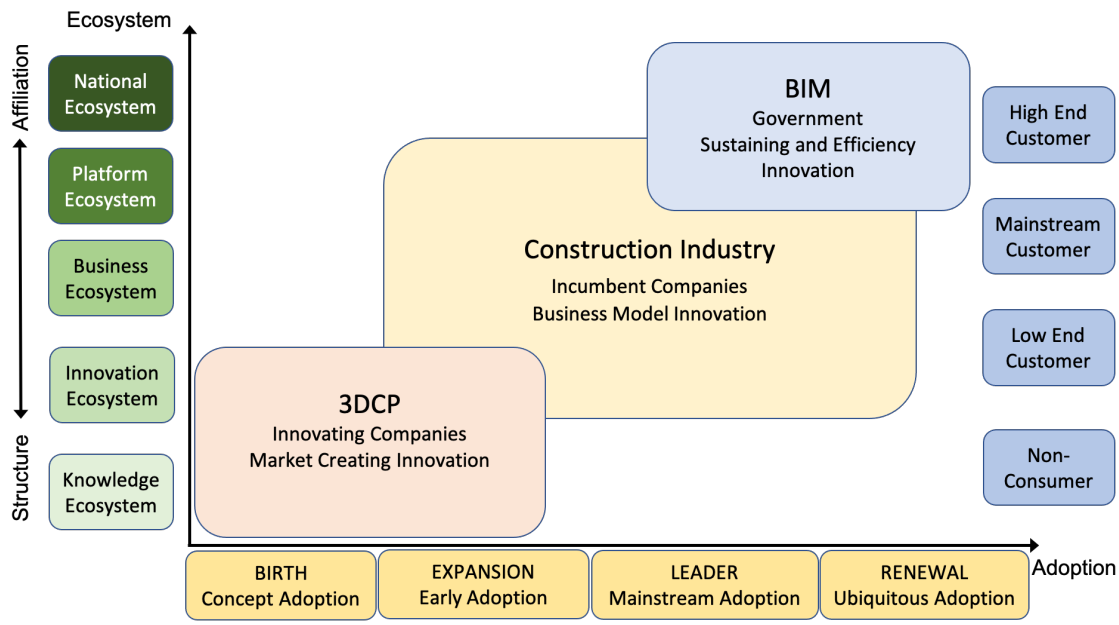


Figure 6.6 Current status of 3DCP and BIM Adoption

Once early adoption has been achieved, companies will need to widen into a more commercial business or platform ecosystem and build key relationships with suppliers, customers and other ecosystem players to enable a broader adoption of the innovation. This is the organic direction of travel from the bottom up.

For BIM, the current status is mainly a government led proposition and their position as the largest infrastructure or high end customer (in effect a keystone player) forces innovation into the industry. This is the top down approach and will affect all players in the construction industry eventually. At present it is mainly high end, large projects that are incorporating BIM, but it will become ubiquitous within the next 3-5 years. It is not market creating as the industry already exists. It is process innovation to reduce waste, increase productivity and deliver more costs efficiency.

Both these innovations are impacting on the incumbents in the middle. Therefore, all industry related companies need to decide what type of disruption will affect them and how to respond to the changing environment. Are they being disrupted by a bottom up, market creating innovation or from a top down sustaining or efficiency innovation? This will allow them to formulate an appropriate response strategy. If it is a top down innovation, such as BIM, driven by a government, consider how to be involved with flagship projects, innovation research and new methods of manufacture, contracting and procurement. If it is bottom up and organic growth to the next level, such as 3DCP, consider if you are in the right ecosystem. Do you have the right partners in their existing network, or should you be searching for new ones?

The existing business ecosystems will react to the disruption to their current environment coming from both ends of the spectrum. Incumbent companies can choose to enter into new network strength arrangements, with both new/existing players, to incorporate both emergent sustaining or efficiency innovations (BIM) or market creating innovations (3DCP) through innovating their business model.

Incumbent firms can choose to pursue a leadership or platform strategy or co-create through current alliances and interdependencies as a follower. The company needs to understand the resource requirements at the outset, to be a platform leader, and a path to build mass adoption in a quick and revenue generative way as well as the boundary conditions it sets to achieve its goals. This will involve business model innovation as well as technological innovation. Business model innovation takes priority, as success with 3DCP (market creating) and BIM (sustaining and efficiency) innovations will still require changes to the existing business model and strategy. Therefore, business model innovation is key for incumbent firms to survive the disruption as they survey the current and future environment.

6.5.2 Understand your Innovation

6.5.2.1 Innovation of Its Time

History is littered with good ideas that never made it to commercial success. The VHS versus Betamax wars for control of television recording, highlights how a superior technical product (Betamax) may not win the commercial battles if the opposition has a stronger ecosystem or value proposition (VHS). The successful launch of iTunes for Apple showcases how an innovator does not need to be first to invent but must be the first to recognise its value and innovate with that invention. It is the combination of various technologies and innovations that leads to the greatest chance of success, therefore both disruptors and incumbents need to be aware of the wider picture rather than just focus on one particular product or process. They must also be aware of the time lag between the various stages of adoption (D'Aveni, 2018) and when a tipping point will move the innovation from concept and early adoption towards mainstream adoption. It has taken 3D printing 30 years to reach its current tipping point. It has taken the timber frame industry and modular housing over 30 years to reach its potential tipping point. Therefore whilst an enabling technology (Christensen et al., 2019) such as BIM or 3DCP is a prerequisite, it will not be successful without complementarities (Kapoor, 2013; Kapoor & Furr, 2015). A new venture will not move from its knowledge ecosystem into a business or platform ecosystem without an

understanding of the market opportunities and benefits its innovations will bring and the collaborators and complementors required.

Companies must also take stock of what type of innovation they are bringing to the existing marketplace. Is it a sustaining or efficiency innovation that is likely to stretch the lifecycle of current technologies and products (Adner & Kapoor, 2016a) and allow incumbents to defend their existing market share for a while longer? Or is it a market creating innovation (Christensen et al., 2019) that will open the sector to a totally new customer, the non-consumer, through the combination of technological and business model complementarities that are finally putting all the ecosystem pieces together (Adner & Kapoor, 2016b)? Therefore, companies must understand if their innovation is disruptive (See Figure 6.7 below).

Type of Innovation	Disruptive	Description
Sustaining Innovation	No	Innovations focused on selling products/services at a higher price for a higher margin. Usually to the same customers in the same market. Example: An iPhone 5 replaced by an iPhone 6
Efficiency Innovation	No	Innovations that allow the same product to be produced at lower cost through use of fewer resources (Labour, capital, material). Example: iPhone 5 produced cheaper by changing manufacturing process
Market Creating Innovation	Yes	Market creating innovations logically create new markets. Disrupt existing markets by creating innovation in products that were previously unaffordable to lower income consumers – non-consumers. Example: 3D Printing
Frugal Innovation	Maybe	*Low end* or *inclusive* innovation that expand a market by focusing on consumers with a low ability to pay. It has obvious link to market creating innovation as both target the low end consumer. Example: Tata Nano car
Open Innovation	Maybe	The pooling of knowledge for innovative purposes where contributors have access to input of others. An approach to innovation within a company which can lead to rapid development of products. Example: Open source software (Linux)
Business Model Innovation	Yes	BMI enables the innovator to capture a large portion of the value with the business model as the source of value creation. Disruptive business models redefine the existing model in search of new ways to create and capture value. Example: Platform business ecosystems (AirBnB, Uber)

Figure 6.7 Summary of Types of Innovation

For 3DCP and modular panel manufacture, the automated machinery used is not new technology and the G-code software to control it has been in other industries for over 30 years. The basic materials of concrete and wood have been used for centuries as building materials. It is the combination of BIM, CAD, automation and process innovation packaged together in a new business model that suggests it is ready for a wider audience as long as it can provide a market benefit. Therefore, it is both technological and business model innovation the 3DCP brings.

For the construction industry that main benefit is all about cost. If these technologies and innovations can reduce costs, then they will be adopted by the wider ecosystem actors. Housebuilders can increase workforce productivity, reduce materials, compress

timeframes reducing pay back and financing times. House buyers get a higher quality, more accurately constructed building at a cheaper cost to a current equivalent house. Governments can house large growing populations at the cheapest cost. Without the cost reduction to compete with traditional construction methods, this industry will not become mainstream or ubiquitous. For BIM the cost and access to the software will be key. Whilst larger projects and flagship projects are adopting the BIM level 2 standards, smaller housebuilders and self-builders are non-consumers at this time. For 3DCP, the current costs are projected to fall to equivalent or cheaper comparable cost over the next 2-3 years. Both of these represent innovations of their time that now has all the components to succeed. This is an opportunity for a disruptor or an incumbent with an innovation mindset.

So before embarking on the creation of a business ecosystem, the disruptors must be able to see a cost saving for their innovation in the construction industry whilst still involved in their knowledge ecosystem. Use that research collaboration to think outside of traditional business models and reconsider the whole value chain to innovation technology, processes and business model concurrently. Is the innovation of its time? Are all requisite components, players and complementarities available now? If not, it is not yet an innovation of its time. If yes, then invest now in creating a proof of concept and an ecosystem strategy.

6.5.3 Understand the Market Opportunity

6.5.3.1 Benefits and Costs

New innovative techniques and modern methods of construction, such as 3DCP, are poised to deliver a range of benefits to the industry (2.3.3 above) but must serve to deliver a benefit to the end customer. With the demographic trends pointing to increased demand for housing and infrastructure over the next 20 years, construction needs to deliver better quality at more affordable prices with cost being the main driver and focus. 3DCP promises to deliver faster, cheaper, resource light limitless designs if it reaches its full potential. BIM promises to digitalise the whole construction process resulting in faster, cheaper, more efficient buildings. Other methods such as mass modularisation and lean manufacturing offer similar promises. All of them can raise the woeful productivity rates of construction by 50-60% and thereby add $1.6 trillion per year to the world's GDP (MGI, 2017). Productivity measures need to be the main KPI for companies to focus the industry on reducing the need to replace retiring workers with more digital savvy left field thinkers. McKinsey see the new normal for construction

will see seismic shifts in the distribution of value creation and capture in the next 5 -10 years, with up to 45% of the $11 trillion current incumbent value pools at stake along with an estimated $265 billion of profits up for grabs to newcomers (MGI, 2020:12). These changes are being accelerated due to COVID-19 with skilled labour being a main concern for incumbents. This will drive a faster adoption of new technologies and create a huge market opportunity.

6.5.3.2 Target the Non-Consumer

The World's population will expand by 2.2 billion to an estimated 9.8 billion by 2050 (United Nations, 2017). They will all need a house to live in and buildings to work in. Yet the global shortfall in infrastructure capacity is estimated to reach $15-20 trillion by 2030. Eliminating this could create an beneficial economic boost of up to 100 million extra jobs and generate an extra $6 trillion a year in economic activity (WEF, 2016). Raising productivity in construction to equal those seen in manufacturing could lead to cost savings of up to $1.6 trillion per year (MGI, 2017:08). This is a huge non-consumer market ripe for a disruptor.

Low and middle income countries represent the most interested early adopters as they see the pressing need to house their growing populations. The vast majority of these countries will snap up any innovation that allows a step reduction in the cost of building homes whilst vastly improving living standards of current homeowners by replacing slums with cheap high quality housing. Those living at the base of the pyramid and currently numbering over 4 billion people can be viewed as a huge untapped non-consumer market for modern methods of construction such as 3DCP.

BIM can also target the non-consumer by expanding its coverage to include smaller builders and self-builders who currently cannot afford the high licencing costs of CAD programs such as Autodesk. Is there an innovative company out there looking to build the digital platform proposed in 5.7.2 above? Is it your company?

6.5.4 Get Noticed

6.5.4.1 Surf the Hype Curve

New ventures need to get noticed in order to attract research funding, incumbent partners and fellow early adopters for their innovation. Whilst it may seem risky to over-promise at inception, companies need to show their passionate belief about the potential of their product. Without overreaching (such as promising to build a 3D skyscraper within the next 2 years), innovators and disruptors can surf the hype curve as a tool to chart their journey from concept to reality. Everyone knows that

entrepreneurs need to be tenacious and determined to overcome technical, financial and regulatory barriers, but with moonshot thinking and stretch targets, huge progress can be made in much shorter timeframes than many incumbents would believe. 3DCP since the first articles in 2003 has, like many innovations, seen a long gestation period however, since the first prototype house was 'born' in 2016, it has seen an exponential rise in interest and technological capability. In the next decade what will construction look like? Depends if you ask visionary disruptors or incumbents. Who would have predicted that teeth straighteners and hip joint replacements would all convert to 3D printing in little over 2-3 years? Moonshot thinking leads to exponential not linear growth.

For innovators in BIM, when will the last paper drawing be used on a building site? Probably much sooner than current incumbents would acknowledge.

So, in building the initial knowledge ecosystems, disruptors should passionately educate and train early adopters, showcase all technical achievements and keep promising the stretch targets.

6.5.4.2 Proof of Concept

For new ventures, it is hard to convince others to share your vision if you cannot see or touch the vision. "*You know a picture paints a thousand words, doesn't it?" (I013_UniAlpha).* An essential goal for innovators in order to attract partners, wider ecosystem players and potential customers is to create early proof of concepts and prototypes to prove the value of the innovation and showcase the benefits.

This is important to all types of potential ecosystem players: Construction firms want to see the machines in action and discuss any technical issues; material suppliers want to see how their concrete sets or slumps: software developers want to test for bugs; architects want to see how their designs look in reality; structural engineers and regulators want to test its solidity; management and accountants want to see the efficiencies and cost savings; whilst developers and house buyers want to make sure it meets their functional requirements and aspirations. Anything new has to be seen and used before it can gain acceptance.

For new ventures at the birth stage of their journey, the knowledge ecosystem they build around them needs to help develop an idea into a tangible product. Research facilities and research grants provided by governments and bodies such as Innovate UK are a main route to providing the knowledge, collaborative community and financing to bring an innovation to a demonstrable stage (See Figure 6.8 below).

Figure 6.8 Proof of Concept: First Approved 3D Building in EU (COBOD 2017)

For incumbent firms, they can also commit part of their workforce to work on collaborative research projects as a Moonshot factory separate from their current operations. Or if it is a sustaining or efficiency improvement within their business ecosystem, they need to partner with a strong player in their current ecosystem to combine their resources with.

For keystone players and platform leaders, they need to ensure that it will positively impact and create value for all in their platform or wider ecosystem. Start small within a flagship project or soft beta rollout before opening up the platform to the open source community to turbo charge its development.

The proof of concept is the best way to get noticed. New ventures can use the hype generated by prototypes as their main marketing tool in the early stages. The construction industry large players will take a backseat to showcasing new technologies so the first mover advantage can be the disruptors. An understanding of the typical path followed along the hype curve or technology S curves gives the disruptor a roadmap to follow as long as they understand where the technology currently is and to know when to use the hype and when to be realistic with the early adopters. 3DCP companies attracted enormous hype in 2016-2018 but it is only now that potential ecosystem partners, and clients are looking for larger scale pilot projects. From 20 buildings until the end of 2019, wait for the exponential rise in examples in 2020/21. The most successful companies have been the most adept at understanding the hype curve and how to use it to their advantage to gain government or private financing for the next stage of development. They have also used this time to build a wider innovation ecosystem, ready for future commercialisation as a business or platform ecosystem player. They have incorporated open days and training videos to

further showcase the concepts being introduced. This is a key complementary skill required to win over a sceptical industry audience

6.5.5 Build Internal Capabilities: Vision

6.5.5.1 Chief Innovation Officer

To encourage an innovative culture within an organisation, the successful company should develop and instil a vision throughout its workforce and the wider enterprise. But how can you action this in a measurable and structured method? For smaller new ventures, this can be achieved through the collective input of the senior executive team and distilled through the remaining employees until a formal structure of the company is viable and necessary. To make a clear commitment to innovation, I propose that all firms either as disruptor, or an incumbent, should create the role of Chief Innovation Officer (CINO). This position should be a senior role reporting directly to the Board or CEO of the company in order to highlight the importance given to this activity within the firm (Figure 6.9).

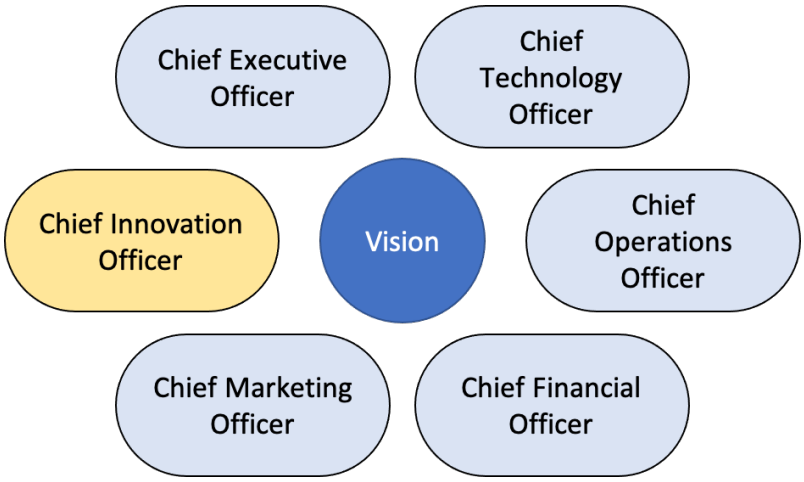


Figure 6.9 Chief Innovation Officer

The CINO does not need to come from a specific industry background nor a particular division, such as technology or marketing, as this role touches all divisions and departments. It should be seen as an advantage if the selected person has a background outside that of the construction industry, free of the residual biases built up over years of interaction with the typical bottlenecks and barriers seen within the construction industry. An outsider can bring free or lateral thinking to the role, highlighting new ideas emerging in other industries and distilling a wide breadth of knowledge of how these new technologies could impact the firm.

The CINO should assemble a small innovation team comprised of a deliberately diverse range of skills and backgrounds to act as a Moonshot or 10x thinking cabal that can work in open collaboration with the existing divisions of the firm. My research as well as the industry literature finds that the most successful disruptive companies have a multidisciplinary background rather than just construction. The CINO should be seen as the orchestrator of the team, not as the generator of all new ideas, as group decisions are vastly superior to individual dictatorial ones especially those that engage in premortem to avoid biases and heuristics (Kahneman, 2011).

This team is tasked to consider all types of innovation to invigorate the firm; new technologies, new processes and new business models. They are tasked with breaking down silos within the firm and its wider ecosystem to allow a more flexible response to disruptions in the industry.

As approximately only 30% of large companies (Lovric & Schneider, 2019) have so far invested in a CINO and only a few in construction, there is a great first mover advantage for a visionary board. The first question to address is how can your company convince others it has an innovative ethos, if it cannot easily showcase it?

6.5.5.2 Business Model Innovation

Companies must adapt to a changing world or risk being disrupted and displaced by new methods of manufacture and business practices. Whilst a CINO and his/her team can present new innovations, business leaders must embrace the culture of business model innovation if they are to survive. Senior executives of new ventures and incumbent firms need to ask themselves how their business model is being disrupted through innovation.

Senior executives need to pose themselves multiple questions: Are we a champion of a new innovation? Is it a sustaining, efficiency or market-creating innovation? How will the new technology be used in conjunction with our traditional methods? Will there be wholesale change or a gradual shift? Will our workers need to be retrained or replaced by others with different skill sets? How will the whole supply or value chain differ with these new innovations in technology and processes? How can I engage with regulators and standards boards to nudge or update the rules of engagement and the working environment to incorporate these innovations? These will all lead to the firm reviewing its current business model and how it needs to be adapted to face the new environment the industry faces.

Separately the company needs to ask how ready it is to adopt open and collaborative strategies; will the firm engage in open innovation and open collaboration policies to

promote the whole sector rather than waste time and effort competing with like-minded disruptors? Greater speed on technological and business model innovations can be achieved through tighter collaborative engagement as has been shown in these research findings.

The important lesson is that innovation is not just about selling printers or software. How will the company train and educate potential clients and other ecosystem players to correctly use the innovation and ensure mainstream adoption and no bad press? The construction market is traditional and slow to change. Will it embrace the innovators as they demonstrate and train them? Or use it as an opportunity to delay change to eke out a few more years from existing business models. This is not a new concept, with the best-selling book "*Who Moved my Cheese?"* (Johnson, 1998) dealing with this dilemma over 20 years ago. Will incumbents accept that someone has 'moved their cheese' and adapt or will they continue with their existing strategies until the exhaustion of all the resources of the company?

To raise awareness and increase acceptance of their disruptive technology, companies must collaborate with research institutes and train key industry practitioners, who are recognised as key players, to promote the technology. To overcome intransigence and resistance from incumbents they must adapt their business models and consider joint ventures and external collaborations (WEF, 2017). To instil a 3D printing approach in their design thinking, the most successful 3DCP companies work with architects, designers, material and hardware suppliers as well as construction firms and other ecosystem players to educate them. To get firms to use their software, the BIM players need to use the latest technologies and techniques across all their projects, not just the government mandated ones.

To capture value from potentially market creating innovations, are companies willing to target non-consumers and open up new business models to serve them?

Companies first need to identify their place in the ecosystem and innovation matrix, then decide if they want to be a platform or business ecosystem leader or follower and understand what that entails. This will determine the type of business model innovation required. Do they have the capital to invest now and are willing to share some of the rewards even if it is only their investment that initially lifts the industry? (Adner, 2012) Are they willing to be a first mover? Are they willing to review the whole value chain and lifecycle of their product and industry?

6.5.6 Build External Capabilities: Ecosystem

6.5.6.1 Collaborative Community

Construction companies operate in an enormous, fragmented industry and often have to collaborate with many partners on large scale projects. This can complicate the adoption of innovations until the majority of the partners are using the same technology or process. Companies therefore need to build trust and collaborate with others in the industry. But how can you get a common or level playing field so that there is a common language and understanding?

This is the role of the wider community or ecosystem. The ecosystem is the platform for disruption where a set of companies innovate towards a shared value proposition. The ecosystem will evolve over four stages of its lifecycle and companies therefore have to employ their ecosystem strategy to consider what role they will play, what complementary markets are required to achieve their value proposition and how the ecosystem will be governed. See Figure 6.10 below for a reminder of some of the main requirements for ecosystem strategy.

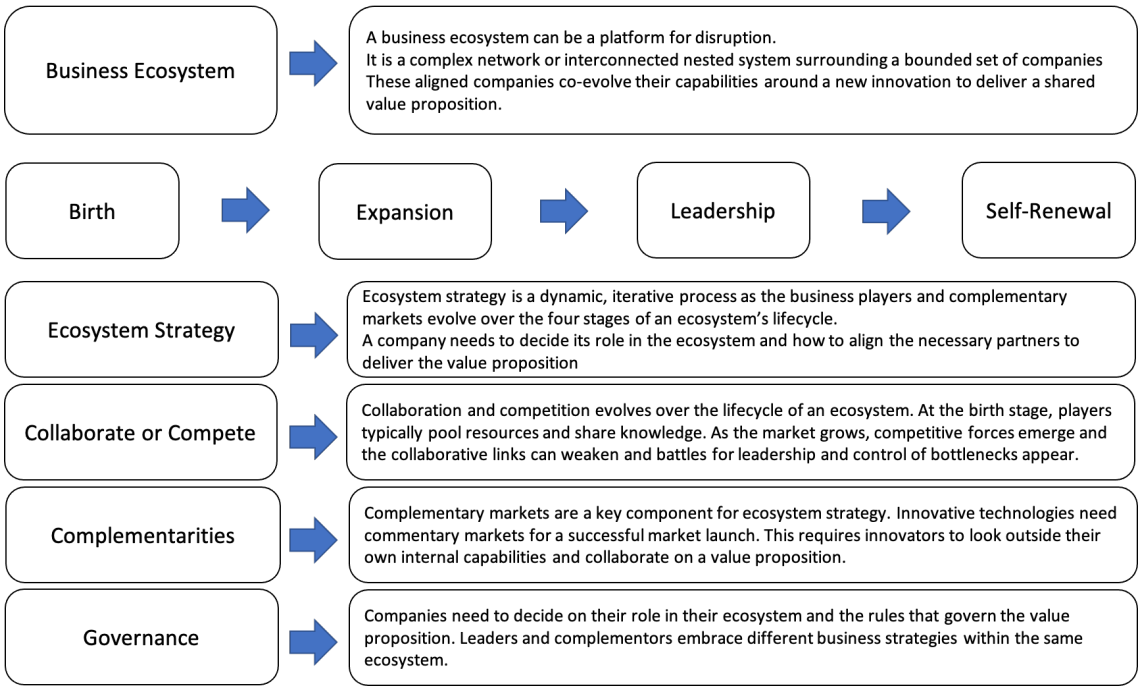


Figure 6.10 Ecosystem Recapitulation

To collaborate new ventures can join specific communities with a common interest in a knowledge ecosystem. This can be through a trade body or industry association for established incumbents, but a trade body should also be a goal for a new innovation as well. Noting the timber frame precedent, rogue firms can easily destroy a technology's usefulness or benefit through shoddy practices or lack of understanding of the product

themselves. Technical committees comprising of multi-disciplinary teams can solve the pressing developmental issues facing the industry and allow the whole industry to grow, on the assumption that a rising tide lifts all boats. It doesn't matter if it's to lift a dinghy or a super tanker, collective power can drive the whole industry much faster than a single firm.

The co-ordination of these committees requires a structure rather than an affiliation whether it is around a flagship project, a specific technical issue or a research institute bringing together the key participants of multi-disciplinary teams to drive lateral and free thinking. This works as long as there is a feeling of equivalence amongst the participants on the committee otherwise the level of trust and engagement will be sub-optimal. The formal governance structure typical for a trade association helps fulfil the requirements for the ecosystem to successfully function.

The complementary components required can be obtained via a collaborative set of partners in adjacent fields including key industry participants who work together to advance the technology and openly share the accumulated knowledge to the wider community. By open innovation and collaboration, trust can be built up amongst the partners who will likely continue to be involved in subsequent projects if the first is successful. Previous research shows these partners duly contribute their complementary competencies to the venture and continue to do so beyond the initial project (WEF, 2017).

Successful innovators also need to engage with regulators to set new standards for an emerging technology such as 3DCP they are seeking to shape the regulatory environment, working closely with construction departments and regulators at a state and national level (WEF, 2017). This can also be achieved at a much faster rate if the community can build a formal trade body quickly.

It is not just technical issues relating to the machinery or software that needs collaborative thinking. Standard contracting and procurement processes are cumbersome and inefficient. Currently most contracts are won at an auction process, and usually won by the lowest bidder, regardless of longer-term cost and performance with the majority of projects coming in over budget and rarely on time. So, regulators, trade associations and project leaders must be engaged at the outset to make the process more efficient, cost effective and sustainable. Early engagement with authorities to create a collaborative and trusting relationship of co-ownership of the project to advance the technology (WEF, 2017). Again, this is best achieved through collective bargaining rather than individual companies making multiple approaches for the same approval.

Collaboration and governance of training and education, as also mentioned in business model innovation, are key to winning ecosystem partners and clients. Whilst it may take a substantial amount of time and effort for a single company to educate potential users, the benefits of a joint approach to regulations, standards, language and marketing efforts can be mutually beneficial to all ecosystem players. This can be driven initially through the engagement of key players at the knowledge ecosystem phase before the industry starts to see early or mainstream adoption.

In summary companies must engage in the wider community and work collaboratively to bring a new innovation or technology to market. This is best achieved by forming a trade body or association at the earliest opportunity to liaise with regulators and adjacent industries at a higher level than an individual new venture will be able to access. By taking this approach the formation of an ecosystem with the requirements for collaboration, complementary markets and governance is more swiftly achieved.

In conclusion, this contribution to practice is a simple six step toolkit based on the findings of this research study for a firm to consider when facing disruption in its sector and deciding on how to address the effects this will have on existing and future business.

6.6 Contribution to Knowledge

So how does this research study and literature review extend, reinforce, challenge, or refine existing knowledge? I have already detailed the extension to knowledge in section 3.9 above, which has been used to help identify the type of ecosystem and type of innovation that companies observe in their industry.

6.6.1 Reinforce

Perhaps I should not be too surprised to find that this research tends to confirm much of the existing knowledge on disruptive innovation and ecosystems, since both fields have been debated and researched over the past 30 years. Construction, as described by many of the interviewees, is still one of the least innovative sectors of industry and therefore a good test bed to observe if Christensen's (1997) and Moore's (1993) theories have relevance. Using the timber frame sector as a previous potential disruptive innovation highlighted how many incumbents have had to move up the product performance and customer segment axis to compete against lower cost companies coming in at the lower end, perfectly illustrating Christensen's innovators dilemma. In the 3D printing sector, the participants highlighted the various stages of

ecosystem development and how adoption by customers follows Moore's expected path as more see the benefits of automated processes with economies of scope as opposed to scale. Again, following the disruptive innovation path, they also started with hobbyists and low-end small scale use, which morphed into larger and more widespread adoption (Laplume *et al.*, 2016).

For the new ventures, collaboration is the key to success in creating and capturing value from their innovation and this study's findings supports the previously researched tensions seen in coopetition (Brandenburger & Nalebuff, 1996) as well as the balancing act between competition or collaboration (Ansari *et al.*, 2016; Hannah & Eisenhardt, 2017) are ever present

The jury is still out on whether 3DCP will develop into a market creating innovation (Christensen *et al.*, 2019), but it has all the potential to do so and further follow up research in the next few years will be useful to confirm this. Time will also tell if I correctly categorised BIM as a sustaining and efficiency innovation rather than a market creating one.

One of the most surprising findings for me, was the near total view that automation was an evolutionary rather than a revolutionary progression for the construction sector. Perhaps the now ubiquitous spread of technology in our daily lives has conditioned people to be more accepting of it and its uses. BIM will not in itself change the construction of houses, but it will change the process and business model surrounding it.

6.6.2 Challenge

The hype curve and technology S curves have not been seen in much of the existing literature on disruptive innovation until recent articles such as Adner and Kapoor (2016a) and Dedehayir and Steinert (2016). However, my research found many of the firms refer to and use these ideas. It was widely used by the 3DCP companies, incumbents in BIM software and 3D printing.

Whilst some research has been conducted into ecosystem genesis (Dedehayir *et al.*, 2018), not enough emphasis has been made by the existing research to consider how a successful ecosystem can be impacted by human behaviour and biases.

When considering ecosystems, the research on the overlap between knowledge, innovation, business and platform ecosystems is still vague. Whilst some have looked at a specific type of ecosystem to try and specifically define what an ecosystem is, only recently have scholars started to compare the differences between them (Gomes *et al.*, 2018; Scaringella & Radziwon, 2018). Research on the transition from one form of

ecosystem to another is sparsely documented apart from a few key articles such as Clarysse *et al.* (2014).

But Clarysse *et al.* (2014) believe that the overlap from knowledge to business ecosystems is not working smoothly as government policies, for his specific case of start-ups in Flanders, did not see a result in a smooth transition from knowledge to business ecosystems. They believe that the value creation processes in knowledge and business ecosystems are fundamentally different, and therefore separate policies need to be tailored for each type of ecosystem. They find public funds tended to be focused on the regional dimension adding little value in building an ecosystem or complex network of relationships across different industrial players. However, their suggestion that large keystone players should be encouraged to apply for public funds to commercialise the innovations is not supported by my research. Innovate UK has been releasing funds to large companies but at the expense of the smaller disruptors. The research bodies I interviewed believed these larger companies tend to crowd out the smaller disruptors which defeats the point of a national innovation system if only the large incumbents win.

Further, whilst I acknowledge Clarysse *et al.* (2014) definition on the three differences between knowledge and business ecosystems, I see more nuance. (1) Knowledge ecosystems focus on the generation of new knowledge whilst business ecosystems focus on value for customers. (2) Knowledge ecosystems are typically a geographically clustered network while business ecosystems are globally dispersed value networks and (3) knowledge ecosystems centre around a university whereas large companies are the keystones of business ecosystems (Clarysse *et al.*, 2014). My research suggests that whilst the 3DCP knowledge ecosystems are generally focused around a geographically clustered network of universities and players, there is also a research community spread across the globe to share this knowledge and the seminars and lectures have drawn together a worldwide community interested in generating knowledge. I also disagree that the knowledge ecosystem is centred around the university. Whilst they are the meeting places for the ecosystem, it is the 3DCP companies that act as the keystones rather than just followers. I also see that these companies are using the knowledge ecosystem as a springboard to develop their business ecosystem and they are not just for the generation of new knowledge. This is the area that requires further research as I see the different types of ecosystem aligned to the stages of growth of companies utilising disruptive innovations. I have seen in my research that there is a progression and there is a different degree of structure or affiliation depending on the ecosystem type and the layer within the nested ecosystems.

I also reflect on innovations of their time. This research highlights how most incumbents (and many of the disruptors) in the construction industry, do not see disruption even though according to the academic definitions, both 3DCP and BIM are innovations of varying disruptiveness. Most saw these as evolutionary rather than revolutionary advances. This challenges some of the literature on creative destruction but mainly supports Christensen, in that existing technologies are mainly used in new business models to provide innovation rather than new inventions. This may be due to the interviewees being immersed in a much more connected, technologically advancing world through their smartphones and tablets, which has made them more used to technology elsewhere in their lives, so now view automation in construction as expected and predictable. But then it brings back why it has taken them so long to consider it? It is only now when these innovations are of their time, that they can make any progress within the industry.

For the question of who will win in the construction industry, disruptors or incumbents, the research is still open to debate. Large incumbents are only just taking an interest in these innovations, both technology and process, and the small ventures are still too new so I cannot yet see who will win as confirmation that Christensen's theory holds true and incumbents get displaced. My feeling is it will be a combination. Platform leaders will emerge in BIM software, although whether it is Autodesk or Microsoft remains to be seen. For 3DCP I think that large incumbents will invest heavily or buy the start-ups to bring the technology inhouse. The bottlenecks of regulation, land and capital requirements will prove formidable for the small companies to breakthrough without an existing player involved (Kim & Mauborgne, 2019; King & Baatartogtokh, 2015). Both disruptors and incumbents can still be successful if they understand their ecosystem type and next steps for their ecosystem strategy. This is why I have now tried to unify the research findings and existing literature on both ecosystems and disruptive innovation as an extension to existing theory.

7 Conclusions

7.1 Introduction

The conclusion makes a clear statement on the discoveries from this study as well as its limitations and relevance. It provides directions for future research and where it has made a contribution to existing knowledge.

According to Tracy (2010:848) meaningfully coherent studies *"(a) achieve their stated purpose; (b) accomplish what they espouse to be about; (c) use methods and representation practices that partner well with espoused theories and paradigms; and (d) attentively interconnect literature reviewed with research foci, methods, and findings."*

I hope this research has achieved its stated purpose. My research question asks***: 'How do new ventures successfully create an ecosystem to capture value from a disruptive technology?'*** Using the case study research method focusing on the ecosystem surrounding innovation in construction, I have interviewed and analysed key actors to produce a data set from which I have constructed a set of practical tools that can be used by disruptors and incumbents. I have used both academic and practitioner existing literature to guide the research study and incorporated their theories and practices to entwine with the findings. I have reached the conclusions only after deliberate and repeated iterative processes to condense down a large amount of data into a workable and simple toolkit, using standard qualitative methods to ensure robustness and validity.

7.2 Outcomes and Contributions

The research aimed to help new ventures successfully create an ecosystem to capture value for a disruptive technology and by doing so make a contribution to practice and theory.

The practical contribution is the toolkit detailed above encapsulating the latest academic literature, industry practitioner reports and the collected research data into a simple framework. Six key themes emerged from the semi-structured interviews, were compared and contrasted with existing and emergent research, produced a set of six toolkit steps under an umbrella ecosystem strategy. This framework was adapted from the adjacent field of strategic management (Freeman, 1984) whilst incorporating the recent work of the father of disruptive innovation theory, Clayton Christensen (Christensen *et al.*, 2019). It explores the emergent theory on how 3D printing has the

capacity to alter existing global value chains and create new economies of scope from manufacturing titans employing new business models (D'Aveni, 2018).

The toolkit consists of an overarching ecosystem strategy with the main analysis on societal impact, a value proposition, and the key actors and complementarities. Companies need to understand the *environment*, the *innovation* and the *market opportunity*. They must also use strategies to *get noticed* by developing *internal and external capabilities*. It is by following these steps that disruptive innovations can be successfully marketed to consumers and thereby capture value.

The contribution to knowledge is also described above but is limited as this is a DBA not a PhD. An extension to the existing knowledge is provided by linking the adjacent fields of disruptive innovation and ecosystems into a matrix. This helps different types of organisation consider the type of ecosystem and innovation they are currently immersed in and where they want to go. It also links the stages of ecosystem growth to the type of structure or affiliation encountered with the typical level of disruption that may occur.

7.3 Limitations

The construction industry is enormous and fragmented, so I make no attempt to generalise my findings across the whole sector. To research innovation within the construction sector is also too large a focus for a single small research study. Instead I have chosen to concentrate on two specific innovations; 3DCP and BIM.

I collected information on 46 companies but acknowledge this is a miniscule number compared with the entirety of firms in the world's construction ecosystem. I interviewed a total of 53 people out of an estimated 100 million involved in construction. Therefore, I make no sweeping statements and wish to avoid overstating the findings.

I would have liked to interview some other potentially key players in both BIM and 3DCP, but many companies did not want to reveal their plans at this stage. Therefore, I accept I may have a non-randomised set of interviews as the companies interviewed could represent only a portion of the actual strategies employed. Concurrently I tried to gain access to the top four UK housebuilders to give a large-scale developers perspective, but I failed to interview any of them. This limited the observation of the response by large housebuilders to the threat to their current industry position, as the 3DCP and BIM technologies democratise the home construction process.

For the 3DCP companies limited data is so far available for triangulation purposes, with many of the companies involved in this study and this industry still in the infancy or ecosystem stage 1 phase (birth or concept adoption). For the BIM players, data was

more readily available, but the fragmented nature of the sector and lack of a keystone player presented a limitation on the observation of any emergent platform ecosystems at this time.

My trip to Africa was extremely useful but again I have only a limited number of interviewees and cannot generalise my findings considering the number of countries, differing outlooks and different stages of innovation present across a continent

Finally, there are a number of 3D construction projects expected to be completed in 2020 but these are too late for inclusion in this research study, especially after the global coronavirus shut down any hope of visiting these sites for inclusion in this research. Follow up research when the lockdowns end and the potential to record the projects will see if this toolkit has proved useful.

7.4 Future Research

I believe innovation in construction is an exciting area for future research studies on disruptive innovation and ecosystems. This is an enormous sector and has many rich areas for both observation and analysis for the creation of new theories and the practical application of existing knowledge. Other areas of disruption in construction include innovators involved in modular housing, automated machinery, augmented reality, mass modularisation and standardisation of components. These are all worthwhile areas for study.

This research study identified several practical problems facing the construction industry. The toolkit needs to be tested against existing key metrics to measure the effectiveness of these tools. Measures on the impact of 3DCP to produce low cost, high quality housing for those in BoP countries should be undertaken for both societal and innovation effects. Existing measures for productivity need to be applied to the modern methods of construction through quantitative research to assess the economic impact on the sector and on a country's GDP.

For ecosystem research, I have linked this study back to network and graph theory, where emergent articles such as Shipilov and Gawer (2020) point to this as an interesting area to explore further. Networks and ecosystems have been recently studied in the natural sciences, so now is the opportunity to apply their research to the social sciences (Fontaine *et al.*, 2011).

I have introduced a matrix that attempts to combine the seminal works of Christensen (1997) and Moore (1993). Much more research could be done to explore this matrix and investigate the transition from one type of ecosystem to another (Clarysse *et al.*, 2014) as well as my introduction of a top down versus bottom up ecosystem

phenomenon. One area to explore is to consider if time for an innovation to reach mainstream adoption is compressed if a top down approach by an ecosystem leader, such as a government is the driver or whether the bottom up disruptor can be quicker through their inherent flexibility. In effect power vs agility.

Further research utilising complexity science (Russell & Smorodinskaya, 2018) and social network theory (Barabasi, 2014) needs to explore the similarities of network effects of platform ecosystems (Cusumano & Gawer, 2002).

And most importantly, practical research is needed into commercialising the 3DCP technology and moving it from concept to mainstream adoption, especially in countries at the base of the pyramid, facing large demographic changes. Building on the recent work by D'Aveni (2018) further research needs to be carried out into how 3D printing could revolutionise manufacturing, including the construction of buildings, to benefit mankind.

7.5 Final Thoughts

On one final note. I have written this thesis against the background of the coronavirus global pandemic. Whilst this has been terrible in terms of both social and economic destruction, I also believe it highlights that the largest ecosystem, the world's ecosystem, is now in Stage 4, Renewal. This is a time of upheaval and disruption but is also an opportunity to invest in market creating innovations.

So if there is one positive I want to say that now is the time to embrace 3D printing and business model innovation For 3D printing in general, the ongoing COVID-19 global pandemic also highlights that now is the tipping point to embrace the economies of scope (D'Aveni, 2018) that 3D printers allow. The benefits of being able to 3D print face masks and personal protective equipment locally, cheaply and to high repeatable quality rather than rely on supply chains that stretch across thousands of miles and sometimes dubious quality from rushed production, shows that 3D printing will see mainstream adoption in the next 12-24 months across all industries and will be included in government level national interest discussions. If some countries decide to slow or even reverse globalisation trends this could lead to renewed onshore manufacturing, lower labour costs, higher automation, with less dependency on international supply chains. Economies of scope not scale, with whole lifecycle performance considered instead of initial low cost through new business model innovation.

Included within this opportunity, let's look to build houses using 3D construction printer technology.

It is an innovation of its time.

Thank you for your time and attention for reading this.

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9 Appendices

9.1 Research Method Definitions

Table 9.1 Theoretical Lens Definitions & Seminal Articles

This is an abbreviated list to provide a taster article/book into different research fields. It is my preferred reading list to remind me of the salient points to recall in each area and in no way encompasses all views in these areas.

Theory	**Seminal Article Authors**
Economic Theory	(Smith, 1776)
Entrepreneurship	(Schumpeter, 1934; Schumpeter, 1942)
Resource Based View	(Barney, 1991; Hamel *et al.*, 1989; Prahalad & Hamel, 1990)
Competitive Strategy Theory	(Porter, 1980)
Strategy Schools of Thought	(Mintzberg *et al.*, 2009)
Stakeholder Theory	(Freeman, 1984; Freeman *et al.*, 2010)
Social Network Theory	(Burt, 1992; Wasserman & Faust, 1994)
Behavioural Economics	Satisficing (Simon, 1956) Bounded Rationality (Kahneman, 2003; Simon, 1979), Nudge Theory (Thaler & Sunstein, 2008) Prospect Theory (Kahneman, 2011)
Institutional Theory	(Scott, 2004)
Paradox Theory	(Smith & Tracey, 2016)
Resource Dependency Theory	(Hillman *et al.*, 2009; Pfeffer & Salancik, 1978)
Strategic Alliances Theory	(Das & Teng, 1998; Das & Teng, 2000a; Das & Teng, 2000b; Das & Teng, 2002)

	(Eisenhardt & Schoonhoven, 1996; Gulati, 1998; Khanna *et al.*, 1998; Ozcan & Eisenhardt, 2009)
Business Ecosystem Theory	(Adner, 2006; Adner, 2012; Adner, 2017; Hannah & Eisenhardt, 2017) (Moore, 1993; Moore, 1996; Moore, 2006)
Disruptive Innovations Theory (Value Network Theory)	(Christensen, 1997; Christensen *et al.*, 2019)
Social Entrepreneurship Theory	(Austin *et al.*, 2006; Hart & Christensen, 2002; Nicholls, 2006; Prahalad & Hart, 2002; Santos, 2012)

Table 9.2 Research Definitions

These definitions unless otherwise referenced are based on *'Doing Business Research: A Guide to Theory and Practice'* by Lee and Lings (2008)

Academic Research	Research to make a contribution to existing knowledge. It must (a) tell us something we didn't know before, and (b) be conducted in a rigorous way. This knowledge can be general or applied to a specific situation (Lee & Lings, 2008:9)
Applied Research	A form of academic research which is aimed at providing answers to a specific problem, as well as contributing to theory (Lee & Lings, 2008:10)
Case Study	Case study – the detailed analysis of a single case (Lee & Lings, 2008:200)
Commercial Research	research aimed at tackling a specific problem for an organisation. What is important is solving the problem. very seldom any 'theory' underlying. commercial researchers tend to be led by the data they collect (we call it being 'data driven') rather than interpreting data in the light of prior theory (Lee & Lings, 2008:9)
Concept	A general idea in our heads about a variable which has a part to play in one of our theories (Lee & Lings, 2008:150)
Constructs	Constructs are formal definitions of ideas we have in our minds about key concepts which make up our theories (Lee & Lings, 2008:155)
Deduction	The process of drawing conclusions from rational and logical principles. In the terms of logic, a valid argument is one in which there is no situation where the principles (which are called premises) are true and the conclusion is not true, and this is a good place to start talking about research (Lee & Lings, 2008:6)
Empirical	The word empirical refers to something which is observable by the senses. In other words, to most intents and purposes, it means observable data from the world around us (Lee & Lings, 2008:8)
Epistemology	Epistemology is the study of what we can know about reality and is dependent in many ways on what you believe reality

	to be (Lee & Lings, 2008:11) Philosophy relating to the theory of knowledge, especially with regard to its methods, validity, and scope, and the distinction between justified belief and opinion (OED, 2010)
Generalisation	The idea that we can apply our specific results to a wider context than just the one that we studied (Lee & Lings, 2008:27)
Induction	essentially the opposite of deduction. It is the process of moving from specific observations to a more general theory (Lee & Lings, 2008:7)
Interpretivism	Interpretive approaches are most concerned with understanding social reality as a construction of the individual participants. (Lee & Lings, 2008:65) P65 They aim to understand the social world, not explain or predict it. Reality is not objective, but rather is a social construction, created within the minds of individuals interacting. One can never separate an individual experience from the holistic sociohistorical context it is part of. Interpretation, and thus knowledge, is never 'final'. Knowledge consists of rich, ideographic description of experiences within their contexts (Lee & Lings, 2008:60)
Model	A model is a descriptive representation of the theory, and by itself offers no explanatory power (Lee & Lings, 2008:123)
Naturalism	The idea that the approaches and methods of the natural sciences are equally applicable to investigating the social world (Lee & Lings, 2008:42)
Occam's Razor	The principle that a theory should rely on as few assumptions, and propose as few hypothetical entities, as possible. It is often expressed as the maxim that 'the simplest explanation is usually the best' (Lee & Lings, 2008:120)
Postmodernism	Postmodernism essentially rejects the idea of any empirical research and focuses only on deconstructing texts to show their contradictory meanings and suchlike.
Proposition	A proposition is a statement that predicts a relationship between two or more variables, one that answers research

	questions and makes predictions (Lee & Lings, 2008:128)
Purposive Sampling	A sampling technique in which researcher relies on his or her own judgment when choosing members of population to participate in the study.
Realist	Believe in an objective world which we can observe and measure. However, there are some things beyond our ability to confirm their existence directly, but yet still have independent existence (Lee & Lings, 2008:31)
Research	The process of generating some kind of evidence with which to support (or refute) your theory generating knowledge about what you believe the world is (Lee & Lings, 2008:6)
Theoretical Sampling	The process of data collection for generating theory whereby the analyst jointly collects, codes and analyses his data and decides what data to collect next and where to find them in order to develop his theory as it emerges (Glaser & Strauss, 2017)
Theory	A theory is a logically self-consistent model or framework that describes and explains how related phenomena behave; it is generally based on, and may be supported by, some kind of observations. A defining characteristic of a scientific theory is that it makes falsifiable or testable predictions about things not yet observed (Lee & Lings, 2008:116)

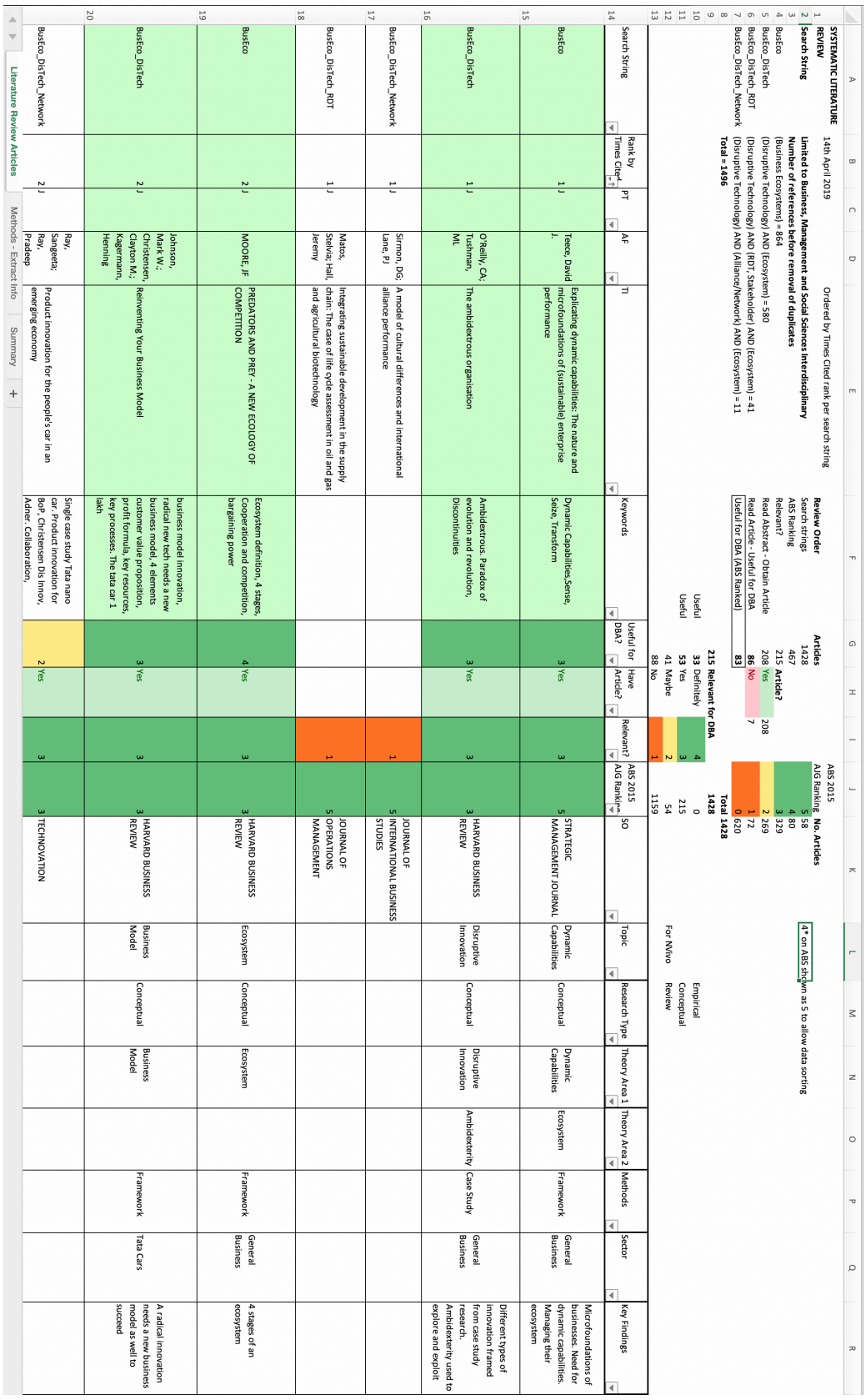
Table 9.3 Coding Definitions

Where not referenced the definition comes from Saldaña (2015:291-296)

A Code	A word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data. The data and thus coding processes can range in magnitude from a single word to a full paragraph or an entire page of text to a stream of moving images (Saldaña, 2015)
Attribute Coding	Notation, usually at the beginning of a data set rather than embedded within it, of basic descriptive information such as the fieldwork setting, participant characteristics or demographics, data format, and other variables of interest for qualitative and some applications of quantitative analysis. (Saldaña, 2015)
Axial Coding	Extends the analytic work from Initial Coding and, to some extent, Focused Coding. Describes a category's properties (i.e., characteristics or attributes) and dimensions (the location of a property along a continuum or range) and explores how the categories and subcategories relate to each other. Properties and dimensions refer to such components as the contexts, conditions, interactions, and consequences of a process. (Saldaña, 2015)
Concept Coding	Assigns meso or macro levels of meaning to data or to data analytic work in progress. A concept is a word or short phrase that symbolically represents a suggested meaning broader than a single item or action, a "bigger picture" that suggests an idea rather than an object or observable behaviour. Concepts can be phrased as nouns and processes in the form of gerunds – smaller observable actions that add up to a broader scheme. Applied to larger units or stanzas of data. (Saldaña, 2015)
Descriptive Coding	Assigns labels to data to summarize in a word or short phrase – most often as a noun – the basic topic of a passage of qualitative data. Provides an inventory of topics for indexing and categorizing. (Saldaña, 2015)
Eclectic Coding	Eclectic coding is basically using multiple first cycle coding

	methods then using a second cycle to focus them into a select method. Employs a purposeful and compatible combination of two or more first cycle coding methods, with the understanding that analytic memo writing, and second cycles of recoding will synthesize the variety and number of codes into a more unified scheme (Saldaña, 2015)
Initial Coding	The first major open-ended stage of a grounded theory approach to the data. Can incorporate In Vivo and Process Coding, plus other methods. Breaks down qualitative data into discrete parts, closely examines them, and compares them for similarities and differences (Saldaña, 2015)
Pattern Coding	A category label ("meta code") that identifies similarly coded data. Organizes the corpus into sets, themes, or constructs and attributes meaning to that organization. Appropriate for second cycle coding; development of major themes from the data; the search for rules, causes, and explanations in the data (Saldaña, 2015)
Structural Coding	Applies a content-based or conceptual phrase to a segment of data that relates to a specific research question to both code and categorize the data corpus. Similarly, coded segments are then collected together for more detailed coding and analysis. (Saldaña, 2015)
Theme	Unlike a code, a theme is an extended phrase or sentence that identifies what a unit of data is about and/or what it means. A theme may be identified at the manifest level (directly observable in the information) or at the latent level (underlying the phenomenon). (Saldaña, 2015)

9.2 Systematic Literature Review Extracts



SYSTEMATIC LITERATURE REVIEW — 14th April 2019 — Ordered by Times Cited rank per search string

Search String
Limited to Business, Management and Social Sciences Interdisciplinary
Number of references before removal of duplicates
BusEco (Business Ecosystem) = 864
BusEco_DisTech (Disruptive Technology) AND (Ecosystem) = 580
BusEco_DisTech_RDT (Disruptive Technology) AND (RDT, Stakeholder) AND (Ecosystem) = 41
BusEco_DisTech_Network (Disruptive Technology) AND (Alliance/Network) AND (Ecosystem) = 11
Total = 1496

Review Order
Search strings
ABS Ranking
Relevant?
Read Abstract - Obtain Article
Read Article - Useful for DBA
Useful for DBA (ABS Ranked)

Articles
1428
467
215 Article?
208 Yes
208
86 No
7
83

ABS 2015 AUG Ranking — No. Articles
5 58
4 80
3 329
2 269
1 72
0 620
Total 1428

4* on ABS shown as 5 to allow data sorting

215 Relevant for DBA
33 Definitely
53 Yes
41 Maybe
88 No

Useful
Useful

4
3
2
1

0
215
54
1159

Empirical
Conceptual
Review

For NVivo

Search String	Rank by Times Cited	PT	AF	TI	Keywords	Useful for DBA?	Have Article?	Relevant?	ABS 2015 AUG Ranking	SO	Topic	Research Type	Theory Area 1	Theory Area 2	Methods	Sector	Key Findings
BusEco	1	J	Teece, David J;	Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance	Dynamic Capabilities,Sense, Seize, Transform	3 Yes		3	5	STRATEGIC MANAGEMENT JOURNAL	Dynamic Capabilities	Conceptual	Dynamic Capabilities	Ecosystem	Framework	General Business	Microfoundations of businesses. Need for dynamic capabilities. Managing their ecosystem
BusEco_DisTech	1	J	O'Reilly, CA; Tushman, ML	The ambidextrous organisation	Ambidextrous, Paradox of evolution and revolution, Discontinuities	3 Yes		3	3	HARVARD BUSINESS REVIEW	Disruptive Innovation	Conceptual	Disruptive Innovation	Ambidexterity	Case Study	General Business	Different types of innovation framed from case study research. Ambidexterity used to explore and exploit
BusEco_DisTech_Network	1	J	Sirmon, DG; Lane, PJ	A model of cultural differences and international alliance performance				1	5	JOURNAL OF INTERNATIONAL BUSINESS STUDIES							
BusEco_DisTech_RDT	1	J	Matos, Stelvia; Hall, Jeremy	Integrating sustainable development in the supply chain: The case of life cycle assessment in oil and gas and agricultural biotechnology				1	5	JOURNAL OF OPERATIONS MANAGEMENT							
BusEco	2	J	MOORE, JF	PREDATORS AND PREY - A NEW ECOLOGY OF COMPETITION	Ecosystem definition, 4 stages, Cooperation and competition, bargaining power	4 Yes		3	3	HARVARD BUSINESS REVIEW	Ecosystem	Conceptual	Ecosystem		Framework	General Business	4 stages of an ecosystem
BusEco_DisTech	2	J	Johnson, Mark W.; Christensen, Clayton M.; Kagermann, Henning	Reinventing Your Business Model	business model innovation, radical new tech needs a new business model, 4 elements customer value proposition, profit formula, key resources, key processes. The tata car 1 lakh	3 Yes		3	3	HARVARD BUSINESS REVIEW	Business Model	Conceptual	Business Model		Framework	Tata Cars	A radical innovation needs a new business model as well to succeed
BusEco_DisTech_Network	2	J	Ray, Sangeeta; Ray, Pradeep	Product innovation for the people's car in an emerging economy	Single case study Tata nano car. Product Innovation for BoP. Christensen DIs Innov, Adner. Collaboration,	2 Yes		3	3	TECHNOVATION							

Literature Review Articles | Methods - Extract Info | Summary

Figure 9.1 Example of Information from Journal Articles

Extracted Key Data from Literature Review Articles

Search String	Rank by Times Cit	Publication Type	Author	Title	Keywords	Topic	Research Type	Theory Area	Theory Area 2	Methods	Sector	Key Findings
BusEco_DisTech	1	J	O'Reilly, CA; Tushman, ML	The ambidextrous organisation	Ambidextrous. Paradox of evolution and revolution, Discontinuities	Disruptive Innovation	Conceptual	Disruptive Innovation	Ambidexterity	Case Study	General Business	Different types of innovation framed from case study research. Ambidexterity used to explore and exploit
BusEco	1	J	Teece, David J.	Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance	Dynamic Capabilities,Sense, Seize, Transform	Dynamic Capabilities	Conceptual	Dynamic Capabilities	Ecosystem	Framework	General Business	Microfoundations of businesses. Need for dynamic capabilities. Managing their ecosystem
BusEco_DisTech	2	J	Johnson, Mark W.; Christensen, Clayton M.; Kagermann, Henning	Reinventing Your Business Model	business model innovation, radical new tech needs a new business model, 4 elements customer value proposition, profit formula, key resources, key processes. The tata	Business Model	Conceptual	Business Model		Framework	Tata Cars	A radical innovation needs a new business model as well to succeed
BusEco	2	J	MOORE, JF	PREDATORS AND PREY - A NEW ECOLOGY OF COMPETITION	Ecosystem definition, 4 stages, Cooperation and competition, bargaining power	Ecosystem	Conceptual	Ecosystem		Framework	General Business	4 stages of an ecosystem
BusEco	3	J	Adner, Ron; Kapoor, Rahul	VALUE CREATION IN INNOVATION ECOSYSTEMS: HOW THE STRUCTURE OF TECHNOLOGICAL INTERDEPENDENCE AFFECTS FIRM PERFORMANCE IN NEW TECHNOLOGY GENERATIONS	Ecosystem strategy, other innovators, focal firm relationship, value creation, components and complements, bottlenecks	Ecosystem	Empirical	Ecosystem	Innovation	Quantitative	SemiConductor Industry	Value creation dependent on ecosystem position
BusEco_DisTech	5	J	Christensen, CM; Bohmer, R; Kenagy, J	Will disruptive innovations cure health care?	incumbent inertia, business models, sustaining vs disruptive innovation,low cost care	Disruptive Innovation	Conceptual	Disruptive Innovation	Ecosystem	Framework	US Health Sector	Rethink practices to allow disruption into US healthcare
BusEco	6	J	Iansiti, M; Levien, R	Strategy as ecology	ecosystem definition, platforms,productivity, robustness, niche creation, keystones, ecosystem strategy	Ecosystem	Conceptual	Ecosystem		Framework	General Business	Need strong inderpendencies to survive. Role of the focal firm or Keystone
BusEco_DisTech	7	J	Amit, Raphael; Zott, Christoph	Creating Value Through Business Model Innovation	business model innovation, definition, Apple as example, economies of scope, 4 major drivers of business models, Interdependency. TOOLKIT -6 Questions to ask. "Look at the forest not the trees' Ecosystems in which they operate	Business Model	Conceptual	Business Model	Innovation	Framework	Apple, HTC, Gillette	Business Model innovation to drive value creation/capture from a new product. Main example is iTunes and Apple
BusEco	7	J	Chesbrough, Henry W.; Appleyard, Melissa M.	Open innovation and strategy	open innovation, open strategy, value creation and capture	Open Innovation	Conceptual	Open Innovation	Ecosystem	Framework	Technology, Software	Traditional strategy needs to alter.Open innovation leads to balance of value creation and capture
BusEco	8	J	Santos, FA; Eisenhardt, KA	Organizational boundaries and theories of organization	Entrepreneurs in new mkts, boundary conditions, nascent mkt definition,claiming, demarcating and controlling a market. Alliances/ecosystem, resources, stakeholders. Power. GOOD DATA SET - USE THIS APPROACH - TOOLKIT	Ecosystem	Conceptual	Organisation Theory	TCE	Theory	General Business	4 Boundary Definitions
BusEco	9	J	Gawer, Annabelle; Cusumano, Michael A.	Industry Platforms and Ecosystem Innovation	Platform Definition, Network effects, keystone firm or platform leader	Ecosystem	Empirical	Ecosystem	Leadership	Framework	Intel	Two types of platform, Internal(company) and external (industry). Keystone player. Platform leadership and how to be effective at it.
BusEco	15	J	Cusumano, MA; Gawer, A	The elements of platform leadership	industry platform, ecosystem, Intel	Ecosystem	Empirical	Ecosystem	Leadership	Framework	Intel	Focus on how to be a platform leader. Four levers to focus on Scope, Product technology, Relationships with externals,

Figure 9.2 Example of Extracted Information from Journal Articles

Table 9.4 Literature Review Articles Breakdown by Method

Method	Count	%
Case Study	30	35%
Framework	29	34%
Theory	14	16%
Quantitative	7	8%
Systematic Review	4	5%
Mixed Methods	2	2%
Total	86	100%

Research Type	Count	%
Empirical	42	49%
Conceptual	36	42%
Review (incl SLR)	8	9%
Total	86	100%

Methods

Business Model	Count	%
Case Study	3	30%
Framework	4	40%
Theory	3	30%
Total	10	100%

Ecosystems	Count	%
Case Study	8	29%
Framework	7	25%
Mixed Methods	1	4%
Quantitative	3	11%
Systematic Review	4	14%
Theory	5	18%
Total	28	100%

Disruptive Innovation/Tech	Count	%
Case Study	19	41%
Framework	16	35%
Mixed Methods	1	2%
Quantitative	4	9%
Theory	6	13%
Total	46	100%

Other	Count	%
Framework	2	100%
Total	2	100%

Dynamic Capabilities, Open Innovation

Table 9.5 Literature Review Articles Breakdown by Theory

Main Topic	Count	%
Disruptive Innovation	40	47%
Ecosystem	27	31%
Business Model	10	12%
Disruptive Technology	6	7%
Dynamic Capabilities	2	2%
Open Innovation	1	1%
Total	86	100%

Theory Area 1	Count	%
Disruptive Innovation	39	45%
Ecosystem	26	30%
Business Model	10	12%
Disruptive Technology	6	7%
Dynamic Capabilities	2	2%
Impression Management	1	1%
Open Innovation	1	1%
Organisation Theory	1	1%
Total	86	100%

Theory Area 2	Count	%
Ecosystem	14	26%
Innovation	7	13%
Business Model	6	11%
3DP	4	7%
BoP	4	7%
Disruptive Technology	3	6%
Strategy	3	6%
Dynamic Capabilities	2	4%
Leadership	2	4%
Open Innovation	2	4%
Ambidexterity	1	2%
Cognition	1	2%
Complexity Science	1	2%
Opportunity	1	2%
Real Options theory	1	2%
TCE	1	2%
Technology Forecasting	1	2%
Total	54	100%

9.3 Enterprise Level Strategy Process (Freeman, 1984)

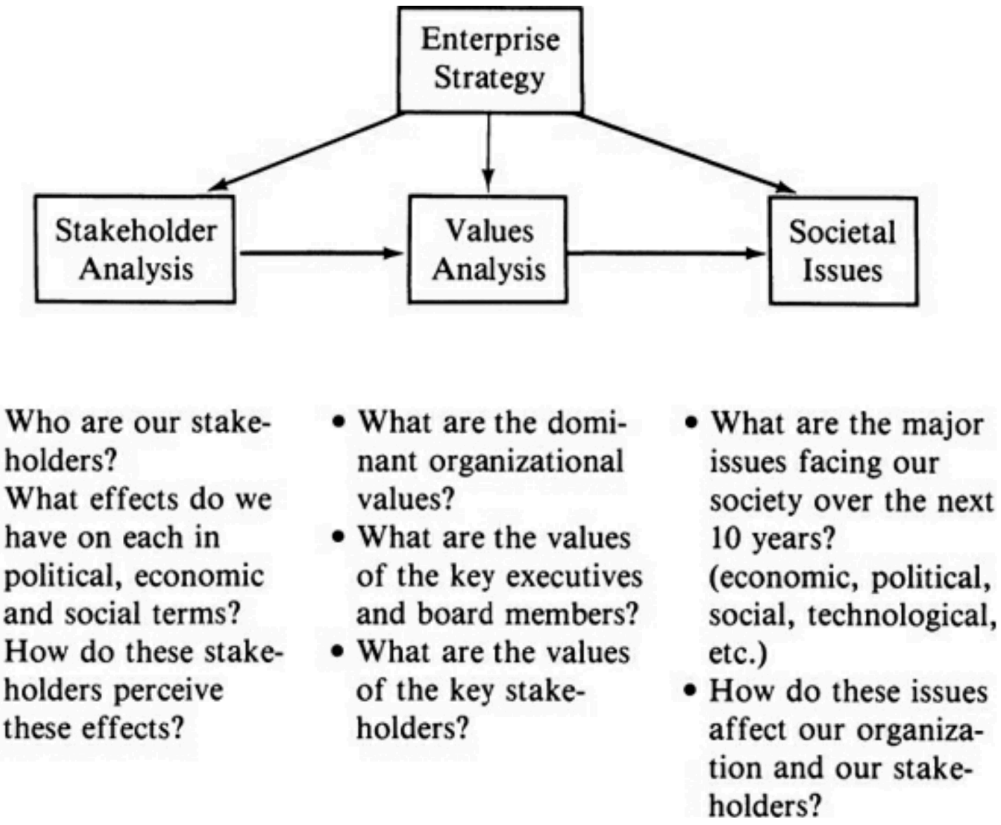


Figure 9.3 Enterprise Level Strategy Process (Freeman, 1984:91, E4.2)

9.4 NVivo Coding Method Maps

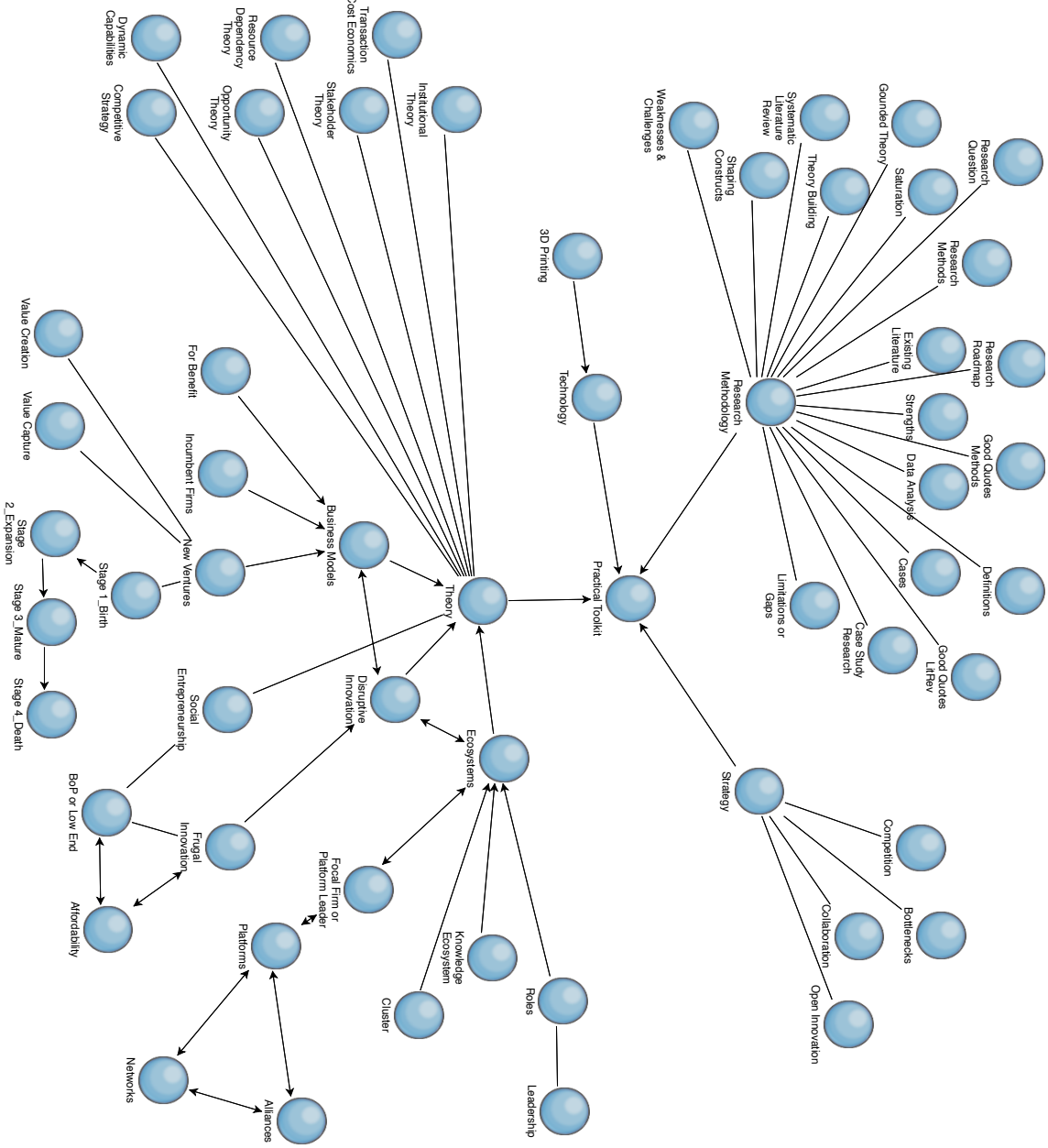


Figure 9.4 NVivo Map of Initial Literature Article Codes

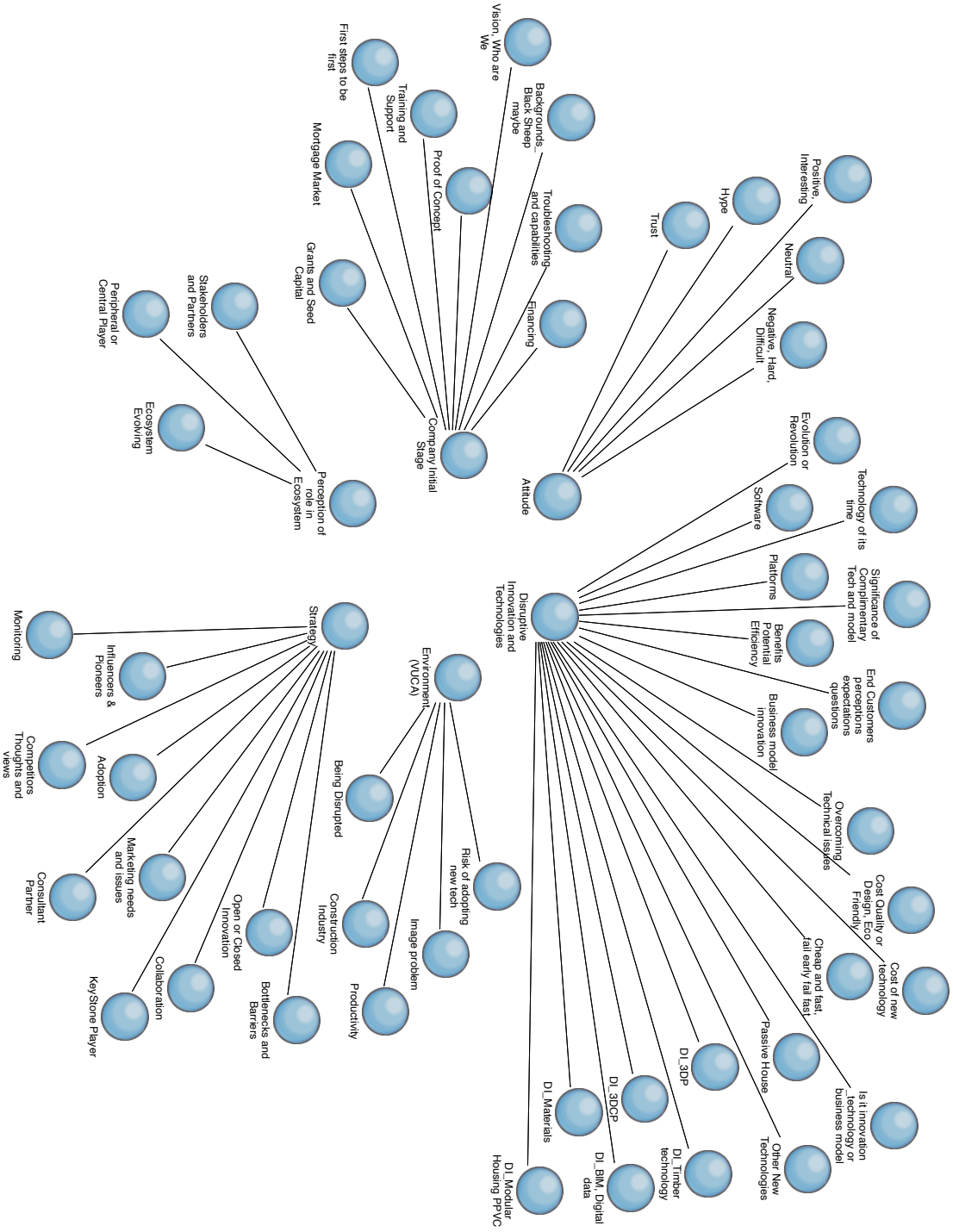


Figure 9.5 NVivo Map of Initial Transcript Codes

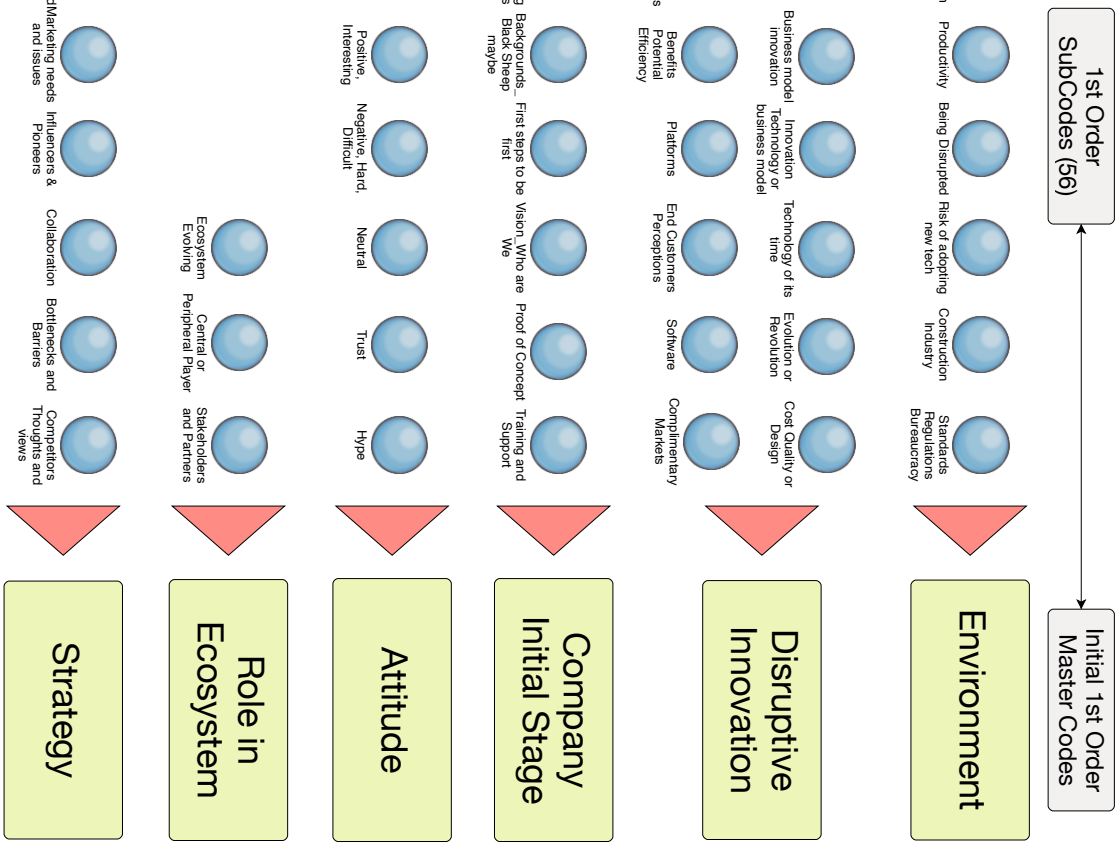


Figure 9.6 NVivo Map of Initial First Order Concepts

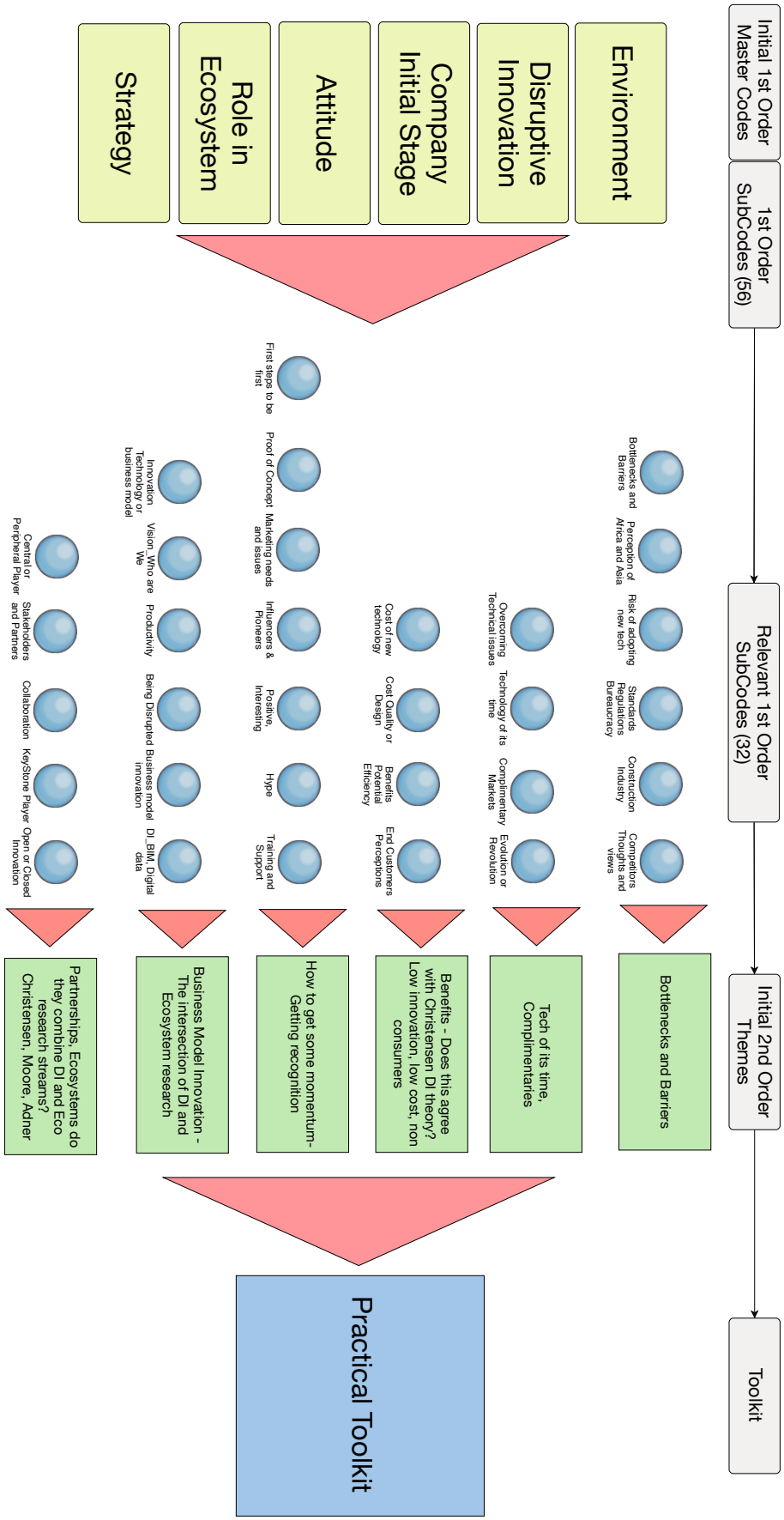


Figure 9.7 NVivo Map of 1st Order Concepts to 2nd Order Themes

9.5 List of Cases and Interview Participants (Anonymised)

Table 9.6 List of Anonymised Case Companies

Company Name	Company Sector	Founder Background	Company Type	Location	Size	Employees	Market	Innovation	Data Collected
3D Alpha	3DCP	Technology	Private	Europe	Small	< 50	Global	Technology	Interviews
3D Beta	3DCP	Construction	Private	Europe	Small	< 50	Global	Technology	Interviews
3D Delta	3DCP	Technology	Private	USA	Small	< 50	Global	Technology	Company Documents
3D Epsilon	3DCP	Technology	Private	USA	Micro	< 10	USA	Technology	Company Documents
3D Gamma	3DCP	Technology	Private	USA	Small	< 50	USA	Technology	Company Documents
3D Kappa	3DCP	Technology	Private	Europe	Small	< 50	Global	Technology	Company Documents
3D Lamda	3DCP	University	Private	USA	Small	< 50	Global	Technology	Company Documents
3D Omega	3DCP	Finance	Private	UK	Micro	< 10	UK	Business Model	Interviews, Diary
3D Phi	3DCP	Military	Military	USA	Large	> 100	USA	Technology	Company Documents
3D Rho	3DCP	Technology	Private	USA	Small	< 50	Global	Technology	Company Documents
3D Si	3DCP	Technology	Private	USA	Small	< 50	USA	Technology	Company Documents
3D Sigma	3DCP	Technology	Private	USA	Small	< 50	USA	Technology	Company Documents
3D Tau	3DCP	Technology	Private	Europe	Small	< 50	Europe	Technology	Company Documents
3D Theta	3DCP	Research	Private	Europe	Small	< 50	Global	Technology	Company Documents
3D Var	3DCP	Technology	Private	Europe	Small	< 50	Global	Technology	Company Documents
3D Xi	3DCP	Construction	Private	Asia	Small	< 50	Asia	Technology	Company Documents
3D Zeta	3DCP	Construction	Private	USA	Micro	< 10	USA	Business Model	Interviews
3DPAM	3DP	Manufacturing	Private	UK	Medium	< 100	Global	Technology	Interviews
CADAlpha	CAD	Software	Public	USA	Large	> 100	USA	Technology	Company Documents
CADBeta	CAD	Software	Private	USA	Large	> 100	USA	Technology	Company Documents
CADGamma	CAD	Software	Private	USA	Large	> 100	USA	Technology	Company Documents
ConConsult	Construction Consultant	Consulting	Private	UK	Small	< 50	Global	Technology	Presentations
ConstructAlpha	Construction General	Construction	Private	UK	Medium	< 100	UK	Unknown	Interviews
ConstructBeta	Construction General	Construction	Private	UK	Micro	< 10	UK	Unknown	Interviews
ConstructGamma	Construction General	Construction	Public	Europe	Large	>100	Europe	Technology	Company Documents
SoftAlpha	Construction IT	Software	Private	UK	Large	> 100	Global	Software	Interviews
SoftBeta	Construction IT	Software	Private	UK	Small	< 50	Global	Software	Presentations
SoftGamma	Construction IT	Technology	Public	USA	Large	> 100	USA	Technology	Presentations
DoorsAlpha	Construction Supplies	Business	Private	UK	Large	> 100	UK	Business Model	Interviews
WoodAlpha	Construction Wood	Timber Industry	Private	UK	Small	< 50	UK	Unknown	Interviews
WoodBeta	Construction Wood	Timber Industry	Private	UK	Small	< 50	UK	Unknown	Interviews
WoodGamma	Construction Wood	Construction	Private	UK	Small	< 50	UK	Technology	Interviews
AfriHouse	Development	Business	Private	Africa	Micro	< 10	Africa	Business Model	Interviews
DevAlpha	Development	Government	Government	Africa	Medium	< 100	Africa	Unknown	Interviews
GovFin	Finance	Finance	Government	Africa	Small	< 50	Africa	Business Model	Interviews
RegBank	Finance	Finance	Government	UK	Large	> 100	Europe	Business Model	Interviews
SovFund	Government Fund	Finance	Government	Africa	Large	> 100	Africa	Business Model	Interviews
HouseDept	Government Housing	Government	Government	Africa	Large	> 100	Africa	Unknown	Interviews
GovPlan	Government Planning	Government	Government	Africa	Large	> 100	Africa	Unknown	Interviews
MortAlpha	Mortgage Bank	Finance	Government	Africa	Large	> 100	Africa	Business Model	Interviews
MortBeta	Mortgage Bank	Finance	Private	Africa	Medium	< 100	Africa	Business Model	Interviews
NGOAlpha	NGO	Charity	Private	USA	Small	< 50	Global	Charity	Company Documents
ResearchAlpha	Research	Government	Government	UK	Large	> 100	UK	Technology	Company Documents
UniAlpha	Research	University	University	UK	Large	> 100	UK	Business Model	Interviews
UniBeta	Research	University	University	UK	Large	> 100	UK	Technology	Interviews

Table 9.7 List of Anonymised Interview Participants

Interview ID	Anon ID	Anon Company	Company Sector	Company Type	Nationality	Position	Date	Time Started	Time (mins)	Type of Interview	Audio File	Transcript Pages	Physical Setting	Participants Clothes
I01	I001	SoftAlpha	Construction IT	Private	British	Chairman	12-Dec-18	1:12:00 PM	33	Face to Face	Recorded	17	Modern Office	Suit
I02	I002	SoftAlpha	Construction IT	Private	British	Chief Operating Officer	12-Dec-18	2:00:00 PM	41	Face to Face	Recorded	33	Modern Office	Suit
I03	I003	Eagle Films	Film-making	Private	British	Film-maker	12-Dec-18	3:09:00 PM		Face to Face	Recorded		Modern Office	Smart casual
I03	I004	SoftAlpha	Construction IT	Private	British	Chief Technology Officer	12-Dec-18	3:09:00 PM	56	Face to Face	Recorded	34	Modern Office	Suit
I04	I005	3D Omega	3DCP	Private	British/African	International Sales Director	30-Jan-19	12:04:00 PM		Skype Audio	Recorded		Unknown Location	Unknown
I04	I006	AfriHouse	Development	Private	African	Founder	30-Jan-19	12:04:00 PM	56	Skype Audio	Recorded	26	Unknown Location	Unknown
I05	I007	3D Alpha	3DCP	Private	European	Communications Director	08-Feb-19	9:57:00 AM	65	Skype Video	Recorded	36	Modern Office	Smart casual
I06	I008	RegBank	Finance	Government Sponsored	European	Principal Banker	12-Feb-19	11:00:00 AM	54	Telephone	Recorded	28	Unknown Location	Unknown
I07	I009	SoftAlpha	Construction IT	Private	British	Group Commercial Director	14-Feb-19	10:44:00 AM	52	Face to Face	Recorded	44	Modern Office	Smart casual
I08	I010	SoftAlpha	Construction IT	Private	British	Chief Executive Officer	14-Feb-19	11:47:00 AM	80	Face to Face	Recorded	54	Modern Office	Suit
I09	I011	UniBeta	Research	University	British	University Academic	15-Feb-19	1:55:00 PM	39	Face to Face	Recorded	20	University	Smart casual
I10	I012	3DPAM	3DP	Private	British	Chief Executive Officer	01-Mar-19	10:12:00 AM	71	Telephone	Recorded	33	Modern Office	Unknown
I11	I013	UniAlpha	Research	University	British	University Academic	09-Apr-19	4:40:00 PM	46	Telephone	Recorded	23	Home	Unknown
I12	I014	WoodAlpha	Construction Wood	Private	British	Chief Executive Officer	11-Apr-19	4:36:00 PM	63	Skype Video	Recorded	28	Modern Office	Smart casual
I13	I015	3D Beta	3DCP	Private	European	Chief Executive Officer	16-Apr-19	1:36:00 PM	120	Face to Face	Recorded	77	Modern Office	Smart casual
I13	I016	3D Beta	3DCP	Private	European	Strategic Advisor	16-Apr-19	1:36:00 PM		Face to Face	Recorded		Modern Office	Smart casual
I13	I005	3D Omega	3DCP	Private	British/African	International Sales Director	16-Apr-19	1:36:00 PM		Face to Face	Recorded		Modern Office	Smart casual
I14	I005	3D Omega	3DCP	Private	British/African	International Sales Director	16-Apr-19	8:51:00 PM	37	Face to Face	Recorded	18	Car	Smart casual
I15	I017	3D Alpha	3DCP	Private	European	Chief Technology Officer	17-Apr-19	10:07:00 AM	120	Face to Face	Recorded	119	Modern Office	Smart casual
I15	I005	3D Omega	3DCP	Private	British/African	International Sales Director	17-Apr-19	10:07:00 AM		Face to Face	Recorded		Modern Office	Smart casual
I16	I018	WoodBeta	Construction Wood	Private	British/African	Chief Executive Officer	18-Apr-19	7:14:00 PM	44	Face to Face	Recorded	20	Home	Smart casual
I17	I019	WoodGamma	Construction Wood	Private	British	Chief Executive Officer	25-Apr-19	10:56:00 AM	50	Face to Face	Recorded	38	Home	Smart casual
I18	I020	3D Zeta	3DCP	Private	American	Chief Executive Officer	01-May-19	4:01:00 PM	57	Skype Video	Recorded	27	Modern Office	Smart casual
I19	I021	ConstructAlpha	Construction General	Private	British	Construction Director	20-May-19	12:39:00 PM		Face to Face	Recorded		Modern Office	Suit
I19	I022	ConstructAlpha	Construction General	Private	British	Chief Executive Officer	20-May-19	12:39:00 PM	112	Face to Face	Recorded	47	Modern Office	Suit
I19	I023	ConstructAlpha	Construction General	Private	British	Construction Director	20-May-19	12:39:00 PM		Face to Face	Recorded		Modern Office	Suit
I19	I024	ConstructAlpha	Construction General	Private	British	Construction Director	20-May-19	12:39:00 PM		Face to Face	Recorded		Modern Office	Suit
I19	I025	ConstructAlpha	Construction General	Private	British	Estimating Director	20-May-19	12:39:00 PM		Face to Face	Recorded		Modern Office	Suit
I20	I026	MortBeta	Mortgage Bank	Private	African	Officer	17-Jun-19	1:53:00 PM	60	Face to Face	Recorded	29	Modern Office	Suit
I20	I005	3D Omega	3DCP	Private	British/African	International Sales Director	17-Jun-19	1:53:00 PM		Face to Face	Recorded		Modern Office	Smart casual
I21	I027	DevAlpha	Development	Government Sponsored	African	General Manager	18-Jun-19	11:52:00 AM	23	Face to Face	Recorded	9	Modern Office	Suit
I21	I028	DevAlpha	Development	Government Sponsored	African	Est Surveyor	18-Jun-19	11:52:00 AM		Face to Face	Recorded		Modern Office	Suit
I21	I029	DevAlpha	Development	Government Sponsored	African	Asst General Manager	18-Jun-19	11:52:00 AM		Face to Face	Recorded		Modern Office	Suit
I21	I005	3D Omega	3DCP	Private	British/African	International Sales Director	18-Jun-19	11:52:00 AM		Face to Face	Recorded		Modern Office	Smart casual

Table 9.8 List of Anonymised Interview Participants (continued)

I22	I030	MortAlpha	Mortgage Bank	Government Sponsored	African	Director	19-Jun-19	4:05:00 PM	65	Face to Face	Recorded	27	Modern Office	Suit
I22	I005	3D Omega	3DCP	Private	British/African	International Sales Director	19-Jun-19	4:05:00 PM		Face to Face	Recorded		Modern Office	Suit
I22	I006	AfriHouse	Development	Private	African	Founder	19-Jun-19	4:05:00 PM		Face to Face	Recorded		Modern Office	Smart casual
I23	I005	3D Omega	3DCP	Private	British/African	International Sales Director	20-Jun-19	12:20:00 PM		Face to Face	Recorded		Government Building	Smart casual
I23	I031	GovPlan	Government Planning	Government Sponsored	African	Department Head	20-Jun-19	12:20:00 PM	30	Face to Face	Recorded	7	Government Building	Suit
I24	I032	SovFund	Government Fund	Government Sponsored	African	Chief Executive Officer	20-Jun-19	1:13:00 PM	60	Face to Face	Recorded	18	Modern Office	Suit
I24	I005	3D Omega	3DCP	Private	British/African	International Sales Director	20-Jun-19	1:13:00 PM		Face to Face	Recorded		Modern Office	Smart casual
I24	I006	AfriHouse	Development	Private	African	Founder	20-Jun-19	1:13:00 PM		Face to Face	Recorded		Modern Office	Smart casual
I25	I033	HouseDept	Government Housing	Government Sponsored	African	Deputy Director	21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I25	I034	HouseDept	Government Housing	Government Sponsored	African	Engineer	21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I25	I035	HouseDept	Government Housing	Government Sponsored	African	Engineer	21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I25	I036	HouseDept	Government Housing	Government Sponsored	African		21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I25	I037	HouseDept	Government Housing	Government Sponsored	African	Director	21-Jun-19	10:05:00 AM	60	Face to Face	Recorded	22	Government Building	Smart casual
I25	I038	HouseDept	Government Housing	Government Sponsored	African		21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I25	I039	HouseDept	Government Housing	Government Sponsored	African	Engineer	21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I25	I040	HouseDept	Government Housing	Government Sponsored	African		21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I25	I041	HouseDept	Government Housing	Government Sponsored	African	Deputy Director	21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I25	I005	3D Omega	3DCP	Private	British/African	International Sales Director	21-Jun-19	10:05:00 AM		Face to Face	Recorded		Government Building	Smart casual
I26	I042	GovFin	Finance	Government Sponsored	African	Chief Executive Officer	23-Jun-19	4:34:00 PM	60	Face to Face	Recorded	28	Home	Smart casual
I26	I005	3D Omega	3DCP	Private	British/African	International Sales Director	23-Jun-19	4:34:00 PM		Face to Face	Recorded		Home	Smart casual
I27	I017	3D Alpha	3DCP	Private	European	Chief Technology Officer	25-Jun-19	5:52:00 PM	100	Face to Face	Recorded	49	Modern Office	Smart casual
I28	I043	UniAlpha	Research	University	British	University Academic	09-Jul-19	9:41:00 AM	51	Face to Face	Recorded	20	University	Smart casual
I29	I044	ConstructBeta	Construction General	Private	British	Founder	15-Aug-19	10:13:00 AM		Face to Face	Recorded		Home	Smart casual
I29	I045	ConstructBeta	Construction General	Private	British	Founder	15-Aug-19	10:13:00 AM	127	Face to Face	Recorded	93	Home	Smart casual
I29	I046	ConstructBeta	Construction General	Private	British	Director	15-Aug-19	10:13:00 AM		Face to Face	Recorded		Home	Smart casual
I30	I047	DoorsAlpha	Construction Supplies	Private	British	Chief Executive Officer	18-Dec-19	11:00:00 AM	91	Face to Face	Recorded	41	Modern Office	Smart casual
P01	I017	3D Alpha	3DCP	Private	European	Chief Technology Officer	01-Dec-19	9:00:00 AM	52	Conference	Recorded	20	University Lecture Room	Smart casual
P01	I012	3DPAM	3DP	Private	British	Chief Executive Officer	01-Dec-19	9:00:00 AM		Conference	Recorded		University Lecture Room	Smart casual
P02	I048	SoftBeta	Construction IT	Private	British	Director Applied Technologies	12-Jun-19	4:05:00 PM	27	Conference	Recorded	8	Conference Hall	Smart casual
P03	I017	3D Alpha	3DCP	Private	European	Chief Technology Officer	26-Jun-19	9:56:00 AM	81	Face to Face	Recorded	25	Modern Office	Smart casual
P04	I017	3D Alpha	3DCP	Private	European	Chief Technology Officer	26-Jun-19	11:30:00 AM	42	Face to Face	Recorded	14	Modern Office	Smart casual
P05	I049	3D Alpha	3DCP	Private	European	Chief Executive Officer	01-Dec-18	Unknown	15	Radio Interview	Recorded	9	Radio Studio	Unknown
P06	I049	3D Alpha	3DCP	Private	European	Chief Executive Officer	19-Nov-16	Unknown	38	Conference	Recorded	13	Conference Hall	Suit
P07	I049	3D Alpha	3DCP	Private	European	Chief Executive Officer	04-Dec-17	Unknown	25	Conference	Recorded	9	Conference Hall	Suit
P08	I049	3D Alpha	3DCP	Private	European	Chief Executive Officer	11-Oct-18	Unknown	42	Conference	Recorded	13	Conference Hall	Suit
P09	I050	ConConsult	Construction Consultant	Private	British	Director	12-Jun-19	1:30:00 PM	35	Conference	Recorded	10	Conference Hall	Smart casual
P10	I051	SoftGamma	Construction IT	Private	British	Chief Technology Officer	12-Jun-19	4:50:00 PM	45	Conference	Recorded	13	Conference Hall	Smart casual
P10	I052	SoftGamma	Construction IT	Private	British	Digital Officer	12-Jun-19	4:50:00 PM		Conference	Recorded		Conference Hall	Smart casual

9.6 Interview Protocols

How do new ventures successfully create an ecosystem to capture value from a disruptive technology?

(a) Overview of Case Study:

This research seeks to identify **how new ventures successfully create a business ecosystem to capture value from a disruptive technology.** The aim of the research is to design and implement a practical toolkit to benefit innovative new firms when deploying a new disruptive technology.

As small innovative firms are less likely to have specialised or co-specialised assets within the firm's boundaries, they are often reliant on a wider ecosystem to enable them to utilize a disruptive technology and capture value from that technology. There is often a fine balance to be struck between collaboration with ecosystem members and competition. My research seeks to gain insight into the strategies a firm may employ in interactions within its industry and with its customers, staff and community when introducing a disruptive technology.

The intention is to use 3DP as example of disruptive technologies as they create 'whole' products with few intermediate processes, resulting in shorter global value chains (raw material extraction straight to 3DP manufacturing of finished goods). It also changes the affordability of the products produced affecting consumption, as it replaces labour-intensive manufacturing processes.

An expected output of this research project is a better understanding of the requirements of a business ecosystem for the successful implementation of a disruptive technology. The knowledge gained will help me design a practical toolkit, including strategies for how to create, shape and utilize a business ecosystem effectively.

(b) Data collection procedures

1. Semi structured interviews with Innovative companies within construction sector
2. Other potential ecosystem players

3. Company Reports
4. Website data

(c) Protocol Initial Themes

1. Your Background and role in the current business
2. The nature of your relationship with key stakeholders
3. Understanding of the ecosystem in which your firm operates
4. Strategies in monitoring and sustaining your ecosystem
5. Disruptive Technologies

(d) Outline for the case study report

Doctoral thesis

1. Practical toolkit
2. Strategies for how to create & shape a business ecosystem
3. Bottlenecks and barriers
4. Impact on Incumbents and global supply chains
5. Funding

Intended for academic and business practitioners.

Thesis to be approx. 80,000 words

Future research to implement findings when building houses in developing countries

Figure 9.8 Case Study Protocol

WARWICK BUSINESS SCHOOL
THE UNIVERSITY OF WARWICK

DBA Programme

Request for Research Study

How do new ventures successfully create an ecosystem to capture value from a disruptive technology?

Robert Brennan

Doctoral Researcher, Warwick Business School

[redacted]

Dear Sir/ Madam,

I am a doctoral researcher from Warwick Business School seeking to develop a toolkit to help new firms deploying disruptive technologies effectively create and utilise business ecosystems. As a business that deploys a potentially disruptive technology, I would like to invite you contribute to my research by agreeing to take part in an informal and confidential interview.

Below I have provided a brief project synopsis, the typical format for the interview and my background.

All participants will receive a full copy of the findings and hopefully you will be able to benefit from the practical toolkit that will emerge from my research.

I hope this research is of interest to you and that you would consider taking part.

Yours sincerely,

Robert Brennan

Project Synopsis:

This research seeks to identify **how new ventures successfully create a business ecosystem to capture value from a disruptive technology.** The aim of the research is to design and implement a practical toolkit to benefit innovative new firms when deploying a new disruptive technology.

As small innovative firms are less likely to have specialised or co-specialised assets within the firm's boundaries, they are often reliant on a wider ecosystem to enable them to utilize a disruptive technology and capture value from that technology. There is often a fine balance to be struck between collaboration with ecosystem members and competition. My research seeks to gain insight into the strategies a firm may employ in interactions within its industry and with its customers, staff and community when introducing a disruptive technology.

The intention is to use 3DP and PPVC as examples of disruptive technologies as they create 'whole' products with few intermediate processes, resulting in shorter global value chains (raw material extraction straight to 3DP/PPVC manufacturing of finished

goods). It also changes the affordability of the products produced affecting consumption, as it replaces labour-intensive manufacturing processes.

An expected output of this research project is a better understanding of the requirements of a business ecosystem for the successful implementation of a disruptive technology. The knowledge gained will help me design a practical toolkit, including strategies for how to create, shape and utilize a business ecosystem effectively.

Interview Process:

- The interview will consist of open-ended questions and normally range between 30-60min.
- Participation is completely voluntary and participants reserve the right to withdraw at any point. All participants are automatically anonymised at the individual and organizational level.
- If participants permit me to I would like to record the interview. Recording interviews enables verbatim transcription by an independent company, resulting in more thorough analysis, compared to that derived from transcripts from notes.
- A copy of their transcript is available for all participants.
- If the participant has any concerns, please let me know before we start.

Potential Interview Themes

- Your Background and role in the current business
- The nature of your relationship with key stakeholders
- Understanding of the ecosystem in which your firm operates
- Strategies in monitoring and sustaining your ecosystem
- Disruptive Technologies
- Any other information

Figure 9.9 Interview Protocol

WARWICK BUSINESS SCHOOL
THE UNIVERSITY OF WARWICK

DBA Programme

Interview Format

How do new ventures successfully create an ecosystem to capture value from a disruptive technology?

Robert Brennan

Doctoral Researcher, Warwick Business School

[redacted]

Tel: [redacted]

Dear Participant Name

Introduction

Thank you for agreeing to take part in this research study.

My name in Robert Brennan

I am a DBA student at WBS

My research area is business ecosystems for firms utilising disruptive technologies.

The Date is ..

I am here with… Participant

Research Thesis

This research seeks to identify **how new ventures successfully create a business ecosystem to capture value from a disruptive technology.**

AIM of the research is to design and implement a Practical Toolkit to benefit innovative new firms when deploying a new disruptive technology.

The intention is to use 3DP in the context of a disruptive technology as it creates 'whole' products with few intermediate processes, resulting in shorter global value chains (raw material extraction straight to 3DP manufacturing of finished goods). It also changes the affordability of the products produced affecting consumption, as it replaces labour-intensive manufacturing processes.

THROUGH semi structured interviews exploring how other companies are building their ecosystem when using 3DP technology to gain insight into the strategies and business models a firm may employ in interactions with its industry, customers, staff and community when introducing a disruptive technology. And mapping the strategy/interactions with internal and external stakeholders

OUTPUT is to design a Practical toolkit and test it if possible in a company through a better understanding of the requirements of a business ecosystem for the successful implementation of a disruptive technology.

The knowledge gained will help me design a practical toolkit, including strategies for how to create, shape and utilize a business ecosystem effectively.

All participants will receive a full copy of the findings and hopefully you will be able to utilise a practical toolkit to allow your company to grow successfully.

As I am also involved with several other companies operating in this space, there may also be business opportunities for your firm to explore.

Explanation of the Interview Process

- The interview will consist of open-ended questions and normally range between 30-60min.
- Participation is completely voluntary and participants reserve the right to withdraw at any point. All participants are automatically anonymised at the individual and organizational level.
- If participants permit me to I would like to record the interview. Recording interviews enables verbatim transcription by an independent company, resulting in more thorough analysis, compared to that derived from transcripts from notes.
- A copy of their transcript is available for all participants.

- Obtain verbal and/or written consent to proceed or answer any questions.

Potential Interview Themes and Questions

Your Background and role in the current business

1. Please could you tell me about **Firm X**, your role and background?
2. What did you do prior to your current role in this organisation?

The nature of your relationship with key stakeholders

3. What organisations and stakeholders do you interact with through your role in **Firm X**?
4. What role does **Firm X** play in the ecosystem/network?
5. Please describe the type of relationship between you and these organisations?
6. How long have you been working with **Firm Y**? What are your reasons for working with **Firm Y**?
7. Do you see this relationship changing in the future?
8. What influenced which organizations you work with?

Understanding of the ecosystem in which your firm operates

1. Do you cooperate or compete against industry firms to support new products and ideas?
2. What inter-organisational dependences do you have with the major ecosystem actors?
3. What is the extent of your collaboration to develop complementary capabilities to create and capture value with ecosystem actors?
4. What kinds of collaborations have occurred between your organizations?
5. How has collaboration between your respective organizations come about?

People? Seminars? Trade organisations?

6. How much influence if any, does **Firm Y** have on **Firm X**? And vice versa?

Strategies in monitoring and sustaining your ecosystem

7. How do you monitor partners and competitors as well as your own development of capabilities?
8. Do you see yourself as the central firm in your ecosystem or a player in a decentred network?
9. Do you see **Firm X** as a pioneer firm?
10. Do you prefer an open or closed innovation approach?
11. What bottlenecks do you see internally and externally to prevent you creating value?
12. Do you have a strategy to identify, control or bypass these bottleneck assets and choke points?

Disruptive Technologies

13. What new technologies are you aware of in your industry?
14. What do you understand BIM to mean (Building Information Modelling) ?
15. What do you think of 3D Concrete Printing? Pre-formed Pre-finished Volumetric Construction (PPVC) or Modular Housing? Cross Laminated Timber (CLT)?
16. Do you believe these technologies are evolutionary or revolutionary?
17. How do you think these develop from an idea to acceptance in the marketplace?
18. How has your ecosystem evolved since using any disruptive technology?
19. Do you think construction industry is being disrupted? Who will be the pioneers in this disruption? Traditional firms? new ventures?

Any other information

- Anything missing?
- Is there anyone else I should speak to?
- Thank you for your time and contribution
- Transcribe notes and send to participant

Observation Protocol

The observation protocol outlined by Savin-Baden & Howell-Major (2013: 398).

Physical Setting: *Room Layout, Style of architecture, Use of space, Activity in that space*
Participants: *What are they wearing? Formal/Casual How quickly do they move?* *General sense of who they are*
Activities: *What activities take place during at the research site? Breakouts area for discussions, games, music*
Interactions: *How do the participants interact with each other – Ranking, informal, tribes,* *Who is 'in' who is 'out' Is everyone engaged? (Texting versus listening or conversing*)
Delivery of information: *How is info delivered? How is info received? Teacher-student, manager to employees, experienced to newcomers*
Subtle factors: *Non-verbal or symbolic communication Pay attention to participants (intonation) and body language*

Figure 9.10 Interview Questions

CONSENT FORM

Title of Project: ***How do new ventures successfully create an ecosystem to capture value from a disruptive technology***

Name of Researcher: **ROBERT BRENNAN**

Name of Lead Supervisor: **DENIZ UCBASARAN**

Date:

Please initial box

1. I confirm I have read and understand the information sheet dated for the above study. I have had the opportunity to consider the information, ask questions of a member of the research team and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. ☐

3. I understand that that my information will be held and processed for the following purposes: to be analysed by the researcher for the purposes of completing their DBA research and, where relevant, for the writing of associated academic journal articles or monographs. ☐

4. I agree to take part in the above named study and I am willing to be interviewed and have my interview audio/video recorded. ☐

_____	_____	_____
Name of participant	Date	Signature
_____	_____	_____

Name of Researcher	Date	Signature

Researcher: Robert Brennan

Supervisor: Deniz Ucbasaran

Date:

You are invited to act as research participant for the above project. Your participation in this project is entirely voluntary. You may withdraw from participating in this project at any time, with no negative consequence to yourself or the organisation for which you work.

This is a research project investigating *how do new ventures successfully create an ecosystem to capture value from a disruptive technology*

The project involves *semi-structured interviews and observation of 3DP projects*

Your involvement in this project will help provide research data for the study.

Participation in this project will involve *an interview*

It is not expected that you will experience any risks through participating in this project. Data will be anonymised from the start, with no names or specific positions recorded as part of the interview material. Your consent form will be stored in a locked office at the University of Warwick, and transcripts of interview data will be anonymised before being printed and stored in the same place. The transcripts will also be stored electronically on the lead researcher's password-locked laptop. All material may be destroyed after 10 years from the completion of the research. The material from this research may be published. You can request a copy of the publication from the researcher named above.

Should you have any further questions about this research, please contact

Rhona Macdonald, Deputy Programme Officer

[redacted]

You may also contact the University of Warwick Research and Impact Services, University House, University of Warwick, Coventry, CV4 8UW, UK (phone: 02476 575732) should you have wish to make a complaint about the conduct of the researcher.

Figure 9.11 Interview Consent Form

Warwick Business School
Doctoral Programme

Research Ethics Form and Checklist

The School is committed to ensuring that the research conducted by its staff and students maintains the highest possible standards of integrity and respects the dignity, rights, safety and well-being of participants. This is why it has put in place procedures for considering the ethical aspects of all proposals for research.

Research students in their first year of registration must complete this form, in consultation with their supervisors, and submit it via *my.wbs* as part of their Upgrade review documentation. Importantly however, this should be seen as a living document. In particular, should your study change in any substantial way following this initial submission (e.g. change in participants, or methods, or a new experiment/research question, or similar), you **must** submit an updated form before starting your research. If you are not clear whether this is necessary, please contact the DPO or the Nominated Ethics Representative. Doing so is not only an ethical obligation toward your participants, but also requirement by the University. **Completion of this form is mandatory for all WBS doctoral students.**

Student name: Robert Brennan

Supervisor (s): Deniz Ucbasaran & Duncan Shand

Title of proposed research project: How do new ventures successfully create an ecosystem to capture value from a disruptive technology?

SECTION 1: HISTORY OF APPROVAL

Is this your first Research Ethics Form submission? NO

If the answer to the above is NO, please tell us in brief about when previous approval was given, by whom, and how this application differs?

First Approval was given in October 2018 before the 2nd Year Progress Report.
The final intention of the research is still to look into 3DCP of houses, but to allow a better base of literature and a wider participation on the subject of creating a viable business ecosystem, the research question has been altered to allow interviews with 3DP companies not directly involved in construction.

SECTION 2: DECLARATION

(A) I confirm that I have read and understand the following documents: X

1. The University's Research Code of Practice: http://www2.warwick.ac.uk/services/rss/researchgovernance/research_code_of_practice/

2. The Economic and Social Research Council's *Research Ethics Framework:* http://www.esrc.ac.uk/funding/guidance-for-applicants/research-ethics/

3. The University's Humanities and Social Sciences Research Committee's (HSSREC) Guidelines for Research Students: **Error! Hyperlink reference not valid.**http://www2.warwick.ac.uk/services/ris/research_integrity/researchethicscommittees/hssrec/student/

(B) I confirm that I (in consultation with my supervisors) have considered the ethical implications of the proposed research project and that it is consistent with the principles outlined in the above documents. X

(C) I confirm **EITHER** (please tick appropriate statement below):

That the research project does not involve direct interaction with human participants or their data (e.g. through interviews, participant observation, survey, or other collection of participant data).

OR

That the research project does involve direct interaction with human participants or their data, and that I have completed Sections 2-4 of this form as accurately as possible as a result. X

Signatures attesting this:

Student: Robert Brennan Date: 09/12/2018

Supervisor 1: Deniz Ucbasaran Date:

Supervisor 2: Duncan Shand Date:

Figure 9.12 Research Ethics Checklist

9.7 Summary of Quotes

Table 9.9 Innovation Bottlenecks Interview Quotes

Construct	Illustrative Quotes	Interview/ Participant	Company
Competitors Collaboration	I felt my number one competitor basically swallowed The Art of War book. There was a lot of misinformation went on. And he took being a competitor very, very seriously.	I10_I012	3DPAM
Competitors Collaboration	A lot of our competitors are companies that are also aiming to start printing concrete…They are competitor, but I've got them on speed-dial…We know what the other people are doing. It's a pretty small community.	I13_I015	3DBeta
Competitors Collaboration	I would say there's still, obviously there's competition, but it's also a very small market. So, we are so few and everybody knows each other. And so, we share a lot. I think in between, obviously not our most valuable secrets.	I15_I017	3DAlpha
Construction Industry	The construction itself and well, the environment generally has been unbelievably slow to adopt new technologies that have come along or even to embrace new ideas. The construction industry is such a broad industry and its massive. For example, building a house in an African village is one thing, building the Gherkin in Central London another.	I08_I010	SoftAlpha
Construction Industry	I always deemed that industry to be quite dinosaur-like in the sense of not adopting new technology.	I11_I013	UniAlpha
Construction Industry	The construction industry is a 12 trillion dollar market, which is still growing. I think currently 3D concrete is, let's say, 10 million dollars…So before it's really getting mainstream. It's just enormous. The construction industry is so enormous. A lot of niche markets.	I13_I015	3DBeta
Construction Industry	Yeah, it's a tough crowd. I think they'll get there, but it will take, it's a very slow-moving industry…It's a very conservative industry.	I15_I017	3DAlpha
Construction Industry	I think the whole industry isn't innovative enough. In fact, the construction sector, having worked in a few sectors, this is absolutely the least innovative of any sector	I30_I047	DoorsAlpha
Construction Industry	This is a very arrogant thing to say, but intellectual capability and cognitive ability of people in the construction sector. What I mean by that is that construction sector is not really the first choice of your graduates, your MBA guys.	I30_I047	DoorsAlpha
Construction Industry	You'll have an IT, CIO of an organisation come in from outside of construction and go, "What have you got here? You're kind of archaic." (laughs) Dirty hands and its pieces of paper and they're sort of aghast by the technology that perhaps is employed.	I03_I004	SoftAlpha
Early Adopter Risk	We certainly haven't moved first. where we're doing that…is in partnership with a, a sponsor, a customer. It's quite a risky strategy to do that, you've got to be very confident that you haven't got it wrong. Because you could invest a fortune in doing it. Again, it's a bit like saying, is you can have a fantastic idea, that you can execute really well, but if the recipient isn't quite ready. It will fail. And the only person that is going to pay for that is you	I02_I002	SoftAlpha
Early Adopter	L&G up in Leeds. Invested 50 million. You don't have ...	I12_I014	WoodAlpha

Risk	you know that, as an investor, you've got to be mad to invest 50 million in an offsite manufacturing business. You're just being mad; you'd just be burning cash.		
Early Adopter Risk	It was too much risk in it for them. let's say that this is the first house, let's say something really went wrong and it collapsed, and something got hurt, someone got hurt. Some of the risks there are with new projects, they just didn't want any part of it. So, I think that's the same for many of the big companies. They don't want to take the risk.	I15_I017	3DAlpha
Early Adopter Risk	It's been an issue where you have some new technology, … you don't find the skilled labour for it or the personnel. …we need to be careful how we are adopting but if we see that we have the partner that has the scale and magnitude of the technology then we are ready.	I21_I027	DevAlpha
Trust	Nothing works without trust, it's a trust of integrity, and a trust of judgment.	I01_I001	SoftAlpha
Standards and Regulations	To get a new material approved to use in construction takes about 10 to 12 years. And so, you've got a battle. If you want to bring something new, like 3D printing for example. You got to get your material.	I08_I010	SoftAlpha
Standards and Regulations	By publishing standards, detailing that gets more people comfortable with it. And it becomes, more embedded, because, the set of rules that people can follow. And a customer specifier is not trying to unpick the differences between manufacturers on their systems. They've got more standardized things that they can understand.	I12_I014	WoodAlpha
Standards and Regulations	We have set our standards test that we wanted for now all of our printers to be EU certified at least…Because then, we know we can go to the Middle East with EU certified, CE certified material, and they will accept it, and we can go to the US, and this certification is one of the you can say the toughest one in the world, so we know that, that everything from then is easy.	I15_I017	3DAlpha
Standards and Regulations	The CE mark transformed things because it unified the standards for a product, which is pretty important.	I16_I018	WoodBeta

Table 9.10 Innovation of its Time Interview Quotes

Construct	**Illustrative Quotes**	**Interview/ Participant**	**Company**
Complementarity	You need all those ingredients for it to work. And the challenge is, whenever one of them isn't in place, it's difficult to make it a success. For us it's refreshing, because what they're doing is, they're saying, I can see you've got these various components that we haven't been able to join up	I02_I002	SoftAlpha
Complementarity	One of the key themes that you see through many, if not all, technology introductions is you get multiple functions coming together as one. I would expect the technology to go from this rudimentary process to something very sophisticated over a number of years, bringing together a number of different things.	P02_I012	3DPAM
Complementarity	We actually see that these technologies are missing, there's not one clear way of doing it. There are multiple ways that this can be combined. They have specific advantages and disadvantages. Could it be	P07_I049	3DAlpha

	that some of these technologies are particularly useful in certain projects? And then some of the technologies are particularly good for other projects. So, in other words that we don't talk about one size fits all here. We talk about different technological solutions to different type of buildings. I think this is the way forward.		
Evolution or Revolution	An interesting thing is that both been around a very, very, very long time. I mean, even back in the late 1980s, people were prefabbing things and manufacturing things offsite in the construction industry.	I08_I010	SoftAlpha
Evolution or Revolution	There's nothing in BIM that people haven't been advising people to do for 50 years in the construction industry. The technology that underpins BIM has been there again for the last 15 years, which is computer aided design.	I08_I010	SoftAlpha
Evolution or Revolution	Even BIM has been around it for 20 years, so it's nothing new.	I15_I017	3DAlpha
Evolution or Revolution	It's not that much of a disruptive technology. We've been making timber-framed buildings for a very long time. The Vikings made timber-framed buildings. This is an old technology; we're just bringing it back and changing it slightly. We've had precast concrete blocks of flats. We've had timber-frames. We've had all these different products that haven't worked.	I17_I019	WoodGamma
Evolution or Revolution	Look what we did in the last 10 years for housing and nothing has changed has it,	I19_I022	ConstructAlpha
Evolution or Revolution	Concrete started with the Romans originally 2000 years ago…No I think the only revolutionary part is the machine can do the concrete 3D printing, whereas timber frame it's not revolutionary is it?	I29_I044	ConstructBeta
Evolution or Revolution	I’ve been in additive manufacturing for 30 years. Most of you may only become aware of it in the last few years, but actually, yes, it has been around for a long time.	P02_I012	3DPAM
Evolution or Revolution	Many think that 3D printing is completely new in construction industry, But, this is a video from San Francisco from the late 30's. He is actually doing very close to what we're doing right now. It's not automated, it's not computerized, but he's actually building layer upon layer of concrete. It's just to show that actually some research's been going on for many, many years.	P02_I017	3DAlpha
Evolution or Revolution	This technology is not new. It's in fact, more than 30 years old. So far, the reason why a lot of people haven't heard about it is that it's being used by the large industrial companies only, and mainly used for prototyping, and also in a few educational institutions.	P06_I047	3DAlpha
Tech of its time	The balance is, is not being too early, not being too late…BIM's a great example of this. We’ll say, what is it you're doing with BIM, what are the plans, etc. Where's the value going to be. How do you want to do it? How can we help. And the answer has been, well, we've got a team looking at it, but we're not really sure. We just know that we need to do it.	I02_I002	SoftAlpha
Tech of its time	There's got to be a delta of common interest…So, you've now got the almost the perfect storm, in a good	I02_I002	SoftAlpha

	way, of having the technology, having the will by the suppliers, stakeholders and sponsors, but also having the buy-in of what was the weak link in the chain. Same is probably going to happen with management of subcontractors…in five to ten years' time people will laugh about, you remember when you used to have to submit a piece of paper to do this.		
Tech of its time	I mean it's interesting all the technology that is needed to do that exists today. You know, you just gotta ask the question. Why aren't they doing it?	I08_I010	SoftAlpha
Tech of its time	We're seeing the beginnings of that happening now, where software is beginning to demystify, the software is beginning to kind of de-art the process.	I10_I012	3DPAM
Tech of its time	It's the same with any new technology. Like the acorn or whatever. It just does nothing for a very long time, and then several things come together at once in terms of capability of the technology, awareness of the need and so on. And it goes from being something that people like me know about, to then you go through a phase where people think it's going to solve all their problems. Of course, it doesn't. then you kind of go through the maturing phases where it starts to become more realistic and people are kind of beginning to look at how they can really get an economic benefit out of it. Same cycle for CAD/CAM. Same cycle probably for building pyramids. You know, it's always … pyramids?!? (that's) never gonna work, is it?	I10_I012	3DPAM
Tech of its time	I think within every project, depending on the design, the process, the people that are involved, another construction methodology is most beneficial. And there were a lot of factors, I've learnt through the last couple of years that are influencing whether a kind of construction methodology is interesting or not.	I13_I015	3DBeta
Tech of its time	I think that yeah, we're gonna start looking as an industry, different ways of building things. And that's where the modularisation and offsite manufacturers does that come into play. So, I think we'll see a lot more of it.	I19_I022	ConstructAlpha
Tech of its time	Imagine where were gonna be in another kind of ten years; mind blowing…you 3D print…you scan the area, you do the design on your computer, you do how he wants it to be with this thing…Slip on your augmented goggles and say this is what it's gonna look like. Okay, you're happy with that? You have a look around. Yeah. Okay. Print.	I29_1045	ConstructBeta
Tech of its time	All the technologies are there it's just bringing the technologies together and so we can create something.	I29_I044	ConstructBeta

Table 9.11 Market Opportunities, Costs & Benefits Interview Quotes

Construct	**Illustrative Quotes**	**Interview/ Participant**	**Company**
Benefits	All technology does is one of two things…The avoidance of negative consequence, and the other one is to achieve a positive outcome, create value by	I01_I001	SoftAlpha

	compressing time.		
Benefits	When we're innovating, we're either innovating in response to feedback or we're looking at how new technology can be used to service those…If you look at the SoftAlpha construction cloud…we're saying how cloud-based technology can disrupt the management and, and payment of sub-contractors and moving away from paper and getting paper out of that system.	I02_I002	SoftAlpha
Benefits	You look at things like off-site manufacture, you look at BIM, and BIM's bit of a more interesting example, but certainly off-site manufacture. We're in that process right now of understanding what it is. Where it's used. What the benefits are. And the challenges. And how we need to respond to that. So, what we do is for example is start to, to hound homebuilders now, who've got off-site factories and saying, well, how's that changed the delivery of how a house gets built.	I02_I002	SoftAlpha
Benefits	I think in the construction process totally, we ought to be able to save both soft cost and constructions costs between 17 to 28%, based on the architectural and engineering, for the architecture, the modelling… In the procurement and supply chain I think there's a significant saving for a business to buy the parts and pieces at a discount	I18_I020	3DZeta
Benefits	Innovation in construction is something very valuable. We're supposed to have that to improve the life of our people	I23_I031	GovPlan
Benefits	Whatever's happened with additive manufacturing is only moved forward when people have found benefits from it. And so, with the construction printing, we're looking for benefits.	P01_I012	3DPAM
Benefits	The five main advantages of this technology. The first is design freedom... Because the printer doesn't care for the printer to print the straight line, or print the curve or a wave... It requires the same effort. So, complexity is for free…And then of course, automation. And we all know that automation has been in industry the last 30 years. And it's about high time that it also hits the construction industry. Because we don't see a lot of automation in construction. With automation comes the possibility of lower cost, higher productivity…Then faster completion time is the third advantage. That's actually something that most construction companies are putting a lot of emphasis on, because it means that we can complete the projects much faster. Because basically, with this technology, we can complete the ground structure within let's say, a week… when we get better at reduction of waste.…And then finally, the ability to use new materials, including recycled materials. What this technology is offering to the construction industry? Well, basically they say three things. They say it's faster 50 to 70%, faster completion is cheaper 50 to 80%, lower labour costs. And it's better because it means we can customise things we can do intricate designs and so on	P08_I049	3DAlpha
Cost	All construction would benefit from cost efficiency by doing more offsite manufacturing and offsite	I08_I010	SoftAlpha

	fabrication…Whether it be using 3D printers or a small manufacturing plant, they would have a dramatic effect on the costs.		
Cost	The only way you introduce it is if it's cheap for the house builders and the house builders are what drive what's being built or by government legislation…But if you're just trying to get into the mass house building sector, it's got to be price.	I16_I018	WoodBeta
Cost	Cost is the driver. We need to know that we can compete in the market, otherwise, it makes no sense	P01_I017	3DAlpha
Cost, Quality or Design?	So how many people copied the show home with all their interiors? …70%	I19_I022	ConstructAlpha
Cost, Quality or Design?	All the questions flow from that. Like, "Well, how do you do it?" "How long does it take?" and "How much does it cost?"	I18_I020	3DZeta
Cost, Quality or Design?	More concerned about the cost rather than quality surprisingly. Cost first, then quality	I21_I028	DevAlpha
Cost, Quality or Design?	I think cost over quality…I mean, cause for most people just want one. They can deal with the quality later…Give us the shelter first	I22_I030	MortAlpha
Cost, Quality or Design?	The key focus of innovation has to be how do we drive down costs, whilst maintaining some decent specifications in liveable home.	I24_I032	SovFund
Market Opportunity	We're currently busy with companies ... in Indonesia, government alone. They are currently in need of ten million houses.	I13_I015	3DBeta
Market Opportunity	There is a lot of places where there are no houses at all. And this kind of technology will kind of build new techniques, new villages, new urban areas…So, if and when this takes off, it will it will be massive	I14_I005	3DOmega
Market Opportunity	There's a market for these houses. As long as they are built well…One of the major things for me in terms of this market is a lot of redevelopment in the war torn areas…a lot of the houses have been decimated. So, this kind of product should be able to produce houses en masse for them. So as much as maybe you might not want to deal with government in terms of those instances, they're the ones who are doing some of those development or the NGOs or the multilateral agencies. Like the ones who can do some of those things. IFC, do you understand to be able to do some of stuff? So those will allow you came to that one story. Yeah. Proof of concept whilst you develop your product.	I20_I026	MortBeta
Market Opportunity	The majority of demand right now are from middle-income to low-income countries where they're looking at building thousands of buildings.	P05_I049	3DAlpha
Market Opportunity	Initially, we thought that we would get all of the attention and all of the interest will be coming from the high cost countries…but likewise, a massive interest from places like Malaysia, India, Philippines, and so on. And the reason there is completion time, because you know, we are involved in customers that are looking at doing a project with 3000 houses at a time. Right now, they're spending six months with this technology, they might be able to do it in one month. So, their completion time comes in.	P08_I049	3DAlpha

Market Opportunity	The Sheik of Dubai has decided that by 2030, it's just in 12 years, 25% of all buildings in Dubai must be 3D printed. 25% in 12 years. Now, he cannot decide that completely on his own. Because that's sort of the market and real estate developers etc. What he can decide is what the Dubai authorities are buying themselves. So, he's put out another measure Another goal that he's told to his authorities that by 2023, that's in 5 years, 18% of all buildings, paid for by Dubai authorities has to be 3D printed.	P08_I049	3DAlpha

Table 9.12 Get Noticed Interview Quotes

Construct	**Illustrative Quotes**	**Interview/ Participant**	**Company**
Financing	Even an Innovate project, if you're a small company, you don't have the capacity to actually run one of those projects in terms of the managing of the project. So again, I think you tend to find your large construction companies tend to dominate getting hold of the money, because they have the capacity to actually be able to manage them. But, of course, they're not necessarily the sort of people that will do the manufacturing.	I09_I011	UniBeta
Financing	If you don't get anybody to fund you, it's a big problem and that certainly was a big challenge for me all the way through with 3DPAM was that getting funding to grow the company was a nightmare. It all had to be organic and that really does make life very difficult.	I10_I012	3DPAM
Financing	I've conversations … they're like, "Oh yeah, we want to do this. We want to do this," so, "Okay. Put up some money," and you never could get them to put up any money.	I18_I020	3DZeta
Financing	We applied for some government grants for researching this. We actually got a 3 year grant for researching state of the art all 3D construction printing globally with the aim of bringing that information about the state of the technology to the construction sector.	P05_I049	3DAlpha
Hype	Yeah indeed they're making massive statements, like Kennedy, “I put a man on the moon” and they only do this in order to get all the governmental agencies, get them crazy That's why I'm laughing because he was like a 35 square meters printing within 24 hours. It actually took like four months indeed and then he got this investment, millions, with no customers	I13_I015	3DBeta
Hype	In general, I think you've noticed that's all, that's a lot of hype in this industry. There's been a lot, a lot of hype. Like there were these guys from a company called Cazza. They're bankrupt now but they promised to build skyscrapers in Dubai by 2022 with 3D printing. And we're like, "Okay, that's interesting. How would they do it?" We talked to him, and they had an app. And it's like, "All right. There's a long way to go from there to building skyscrapers.” There was nothing, they had nothing.	I15_I017	3DAlpha
Hype	It's very difficult to divide hype from reality because	I15_I017	3DAlpha

	there are still a lot of hype… that's the reason we visit every site…because then we can see with our own eyes what is going on, what is being printed and what is being done. I think people have been economical with the truth when they've been pushing them what they have reached.		
Hype	3D Delta Well, you know, I went there two years ago to buy their equipment. And when I got there, I found out they really didn't print the house in one day. Four months. Four months (laughs).	I18_I020	3DZeta
Hype	There's a lot of hype about this. This is the Gartner hype curve… it basically says that a new technology is coming. Early Adopters are investigating, mass media starts to write about this. And everybody thinks that now we have a 3D printer in our own houses or 3D printers will build all the buildings in the world. And then people… start to realise, you know, this house was not printed in 24 hours, or no, we will not print skyscrapers in 2022. And then we have a big disappointment. And then we see really the steady development from there on. Where do I think we are? I think we are around here. And I think this will happen. If we have more of these stupid claims about what can be done, I'm sorry.	P07_I049	3DAlpha
Hype	In February 2017, they said we 3D this building in 24 hours. No, it took four months. Still, it's a good building, but there was just too much saying that was done in 24 hours, I asked … the CEO, “Why did you come out and say this? You know? That's not true, obviously.” “Nah, you know, it could have been true.” And there's actually a lot of sense in what he is saying, it could have been true if we didn't f… up so much. We did the same with our building because it's bloody difficult to do something the first time right, think about how good you were when you drove a car first time. Does that mean the car was bad? No. It meant you were bad as drivers? Same thing here. Same thing with his car. So yes, it could have turned in 24 hours, if they hadn't gone into various kind of problems that they didn't expect and various kinds of things that they hadn't sort of prepared for. So, in that sense, he was correct.	P08_I049	3DAlpha
Influencers and Pioneers	Look at AutoDesk. You know, look at where AutoDesk started. They were just a Mickey Mouse little unit that just said we'll give our software away for practically free…Look at them now	I10_I012	3DPAM
Influencers and Pioneers	I was chairman of that industry association for a couple of years… I ended up managing the industry through that…it actually has clout and it has quality control…it made me get the industry some teeth to it…So we're an expert in our field.	I12_I014	WoodAlpha
Influencers and Pioneers	Trade body of 3D concrete printing it is way too early. We don't even have a like a branch organisation…There's definitely discussions across the companies and the universities and the borders. Especially in Europe…But there's no like single body that starts to discuss all of these things…So we don't have a common language. So, like the same thing can	I27_I017	3D Alpha

	be called like four different things in different companies at different universities.		
Influencers and Pioneers	So, there's no industry, there's no organised efforts toward this. There's a lot of different players who wants different things and so on. So, but I believe it will come and how fast, it's really a matter of who is pushing forward. So, you could say our investor and collaborative partner on this is I think because they're representing the industry, I think they will definitely, because in order for them to push this technology, they will need to have some standard.	I27_I017	3D Alpha
Influencers and Pioneers	I think everyone who works within 3D printing and construction is currently present more or less in Dubai, because we believe that this will be the region that actually commercialise this technology. The sort of the first because the Sheik of Dubai… said that in 2030, 25% of all construction should be a 3D printed. Exactly what that means specifically, this really is it's not been specified	P02_I017	3D Alpha
Initial Steps/ Research	There are some early adopters we're talking to. One of our large customers is just started going down that prefab route. And we are talking to them, well what's it means in terms of how we're going to help you service sites	I02_I002	SoftAlpha
Initial Steps/ Research	It was slow…you know you have to convince that first organisation to go, to go with it. I guess they pilot, they start small. And they try it out maybe on one division. It's difficult to get started, because first thing you need is land and that's pretty expensive (laughs).	I03_I004	SoftAlpha
Initial Steps/ Research	The second mover normally becomes the most successful rather than the first mover… What the first mover very often lacks. First Mover tends to be, particularly in our industry, high with technical people that have never sold or marketed anything where I've got a great idea what the second mover does is, they see that there's something happening in the marketplace and are much better at marketing and positioning that product in the marketplace.	I08_I010	SoftAlpha
Initial Steps/ Research First Mover	As somebody ... as the guy who bought the dental technology off us ... They bought all of our know-how for a not too princely sum. And his comment was, "It's the second mouse that gets the cheese." The person who does the hard bit almost always doesn't get the credit or the money. Or anything. And second or third one in that's either stolen the idea or bumped off the (laughs) first person or whatever is the one who wins. So, you know, that comes down the more aggressive side of business life. And I'm afraid I probably fall more into the first category of thinking “hey this is a great idea” and tell everybody about it as opposed to being smart.	I10_I012	3DPAM
Initial Steps/ Research	But, as always, it takes a lot of time for, for new technologies to actually be implemented somewhere. Probably with additive, I would say initially it just follows a standard S curve really. So, initially, it was very slow development and things didn't really move much. And then it went through a very rapid increase in productivity, which was function in materials and	I10_I012	3DPAM

	function of the amount of research being done into it from an educational technical point of view. But, ultimately, now, it's about how much money people are throwing at it. And it goes into the S curve, and ultimately, it's a lot of little S curves.		
Initial Steps/ Research	I showed him a 3D model of the houses and he went, "Oh, it's, BIM. Not for us". (Laughs) and now we are starting to see it. But they're only very early days of introducing it. And, they're trying to find their way. So, we're helping them the best we can. You know, we can provide 3D models. You know, we can import into BIM, but they can't interact with them.	I12_I014	WoodAlpha
Initial Steps/ Research	I started to develop the technology myself. First, we developed the technology. Later on, we entered an accelerator program about, okay, so now that you have the technology, but how are we going to make business out of it? Are you going to sell the printers, or are you going to print yourselves? But that some agencies they set out open tenders. We together with the consortium submitted, our bid. We won based on that first project, second, third... And later on, like last year we started selling the printers. And so, what we do is we develop our own technology - the hardware, the software, and the material. Then we went selling also the printers to a Japanese construction company or to the Middle East and worked with a Spanish construction company. And then we understood ... It's actually not about printing. Alright, you don't want to have a printer - what you want is to build fast, and affordable.	I13_I015	3DBeta
Initial Steps/ Research First Mover	We realised that nobody was actually talking about building a house in Europe. Then we're like, all right, let's do it. It was like, yeah, we could, we had an opportunity to be the first and to get a lot of media attention from that and so on. And then we just built the printer and tried to print construction material. We went out and marketed it and obviously we knew a lot of the partners within this field because we had done the research before. We followed all their progress very closely to see if we had any competitors to take this title. We figured out the date they wanted to start. And we just set our deadline a week before and then we just went for it.	I15_I017	3DAlpha
Initial Steps/ Research Vision	We are confident than in three years we can maybe, if everything goes well, we can address 50% of the total house with the technology we have developed. Then we can start to talk about prices being reduced into something that makes lot of sense.	I15_I017	3DAlpha
Initial Steps/ Research First Mover	Well, I know how 3DXi did it. 3DLambda just got patents for the U.S. And then, 3DXi followed their patents basically, and then patent it in (other country)…, and then made a billion dollars from the Saudi Arabians, selling plants. Just like "Whatever!"	I18_I020	3DZeta
Initial Steps/ Research First Mover	If you go first and do it well, I guess your chances of failure are higher but if you do well you've reaped the benefit from being first in. But there's a lot to be said for fast followers isn't there because you can just tweak it to not make the same mistake then. but then I	I28_I043	UniAlpha

	guess the ones who go to market first and becomes synonymous with market, if their successful. That's my take on it, All the good ones tend to be ones that are open up and actually quite and honest about what they are doing and recognize actually speed is their asset. So nowadays a lot of SME's going to be first to market…They recognize they only have a limited window of opportunity to exploit to it before somebody pinches it and runs off with it		
Initial Steps/ Research Bottleneck	It's a process, process approval or certification or whatever, is critical. The first step. Once you've done that, okay you're in. But until you've done that, it's nowhere.	I10_I012	3DPAM
Initial Steps/ Research	We are still here. Exploration mode, done by innovators, the market is small, prices are very high, sales is very low, competition is low. And what are we all hoping to get? More awareness, this is really an emerging market. Let's not kid ourselves. It's not mass market, is far from that. We're talking about a new technology curve. Yeah, this is a normal S curve theory, right where it says you have a new technology, you get better and better using it at a certain point, you cannot be to get more out of it. This is a conventional industry took hundred years to get to here. Here is 3D printing, we start lower, very logically, we start lower, we have the potential to grow much higher. So, what I'm actually saying is, we are not competitive. And the reason why we are not competitive is this. Nobody has experience, We're still on this sort of learning curve. And we have no scale effects.	P07_I049	3DAlpha
Marketing Issues	I'm trying to get our sales team to not deal with customers that don't know what the technology is because it's a waste of their time. There's plenty of people out there who understand enough to at least be kind of on stage two and start thinking about their strategy for using the technology. So that's just one of those big challenges you got to be hard-nosed about it and not waste your time on people who that aren't gonna be spending the money with you. We did far too many years of that, really.	I10_I012	3DPAM
Marketing Issues	The early 80's and then there was some bad publicity because … the new technology and it was Barrett's at the time who hadn't constructed the product right, but it was nothing to do with the timber frame but the industry because of this Barrett quality issue got trashed.	I12_I014	WoodAlpha
Marketing Issues	It's very rare these days, that I would go into a virgin patch without the client wanting to do it. I won't be going in, it's a waste of time to try go to the developer who's built all his life in masonry. And, we are there to try and sell them timber frame. Forget it, it's just not worth it.	I12_I014	WoodAlpha
Marketing Issues	You've got to hard sell. It's not just bringing the technology and then making it and thinking that's great, at the end of it somebody's got to buy it. And if you're not ... If people don't like it, you're not going to	I17_I019	WoodGamma

	sell it		
Proof of Concept	For this to work, there needs to be some form of prototype on display in the country…A prototype house on the ground that can explain, physically, all of these issues that I raised will be very helpful.	I04_I006	AfriHouse
Proof of Concept	The proof of concept. Yeah, that's been most important, that we actually built a house…It's here, it's a physical thing. So, it's not just a promise anymore	I15_I017	3DAlpha
Proof of Concept	It's like everybody asks the same two questions, is, "Have you built one yet?" and "Can you get a permit?" So, we're building on a very difficult lot, and we're doing that to showcase the technology	I18_I020	3DZeta
Proof of Concept	I need to see. It would need to understand it. Will all be proof of concepts?	I20_I026	MortBeta
Proof of Concept	What we are doing with other technologies is providing space for some samples and more sort of like we have sites, kind of do that crazy, a small plot style, a few homes if you will, to see how, how it works	I24_I032	SovFund
Proof of Concept	Conclusion for this point is that we have proven the potential. So, we have shown that is definitely savings to be made there. That is market potential. And there's definitely a way into doing this. But we need to do more projects, we need to learn more, we need to get out there and do it. So that's what we're doing	P02_I017	3DAlpha
Proof of Concept	We did the building to prove that our technology worked. And we will do other projects in the future for the same reasons.	P05_I049	3DAlpha
Training and Support	I would say probably 60-70% of sales teams' time was spent just explaining the technology. Time and time again… it's been a very big educational challenge.	I10_I012	3DPAM
Training and Support	Also, with partners that we work with. We educate them, we focus heavily on education with 3DBeta Academy.	I13_I015	3DBeta
Training and Support	We need to set up a training program so I'm documenting it every day, how many people were on site, what did we use, what have we accomplished, pictures, all that sort of thing. So we can then go out to, you know, a professional trainer, and have them, basically take what we've put together in terms of content and, not only how to build a house, but then we have to incorporate how to take care of the printer and if this breaks, what do you do. What's the procedure?	I18_I020	3DZeta
Training and Support	It's been an issue where you have some new technology, the content that we would like to do. You know, you don't find the skilled labour for it or the personnel	I21_I027	DevAlpha
Training and Support	One of the things that that's affected the introduction of even the evolutionary building technologies in (Africa) is a lot of our workforce have been trained for many years used to the traditional brick laying. So, the mindset of accuracy from the beginning is not there	I24_I032	SovFund
Training and Support	I think that any of those things needs to obviously there is a capital investment in the technology itself, but also significant training and development for your workforce. Otherwise you do the panel perfectly in the factory and the guy who has to go onsite makes a dog's breakfast of it.	I24_I032	SovFund

Training and Support	We have a full manual, it's actually online as well. It's on the website. So, we have to do some training manuals. Just like it's user manual, you could say. So that's like step by step processes of that's like everything that should be in a CE certified machine. So, there's like all the legal stuff, all the boring stuff. And then there's like a step by step guide of installation. There's a step by step guide of how you use it, what software you use, where you can find documentation, everything like that	I27_I017	3D Alpha

Table 9.13 Vision & Business Model Interview Quotes

Construct	**Illustrative Quotes**	**Interview/ Participant**	**Company**
Being Disrupted	You're no longer theoretically going to have, bricklayers on site building houses. You will have people with spanners and socket sets coming and bolting them together. A lot of the house builders are only just starting to understand that themselves. So, again, they're slightly further along the curve than us.	I02_I002	SoftAlpha
Being Disrupted	So, we're quite an attractive partner for…people who are offering …complementary services that would be very attractive. Clearly, if they're offering things that overlap, then we start to say, "Hmm. Not so sure about that." Because you might threaten what we do, because it's a means of intruding or getting in there. You know, they're like, "We don't touch your bits." Then there's the inclination to say, "Oh, well, we could just expand what we do and push out SoftAlpha	I03_I004	SoftAlpha
Being Disrupted	But it does beg the question in the construction industry, coming back to why when offsite manufacturing has been around, from the late 1980s and it's still not taken off in the mass market.	I08_I010	SoftAlpha
Being Disrupted	I don't see in our markets 3D printing as a serious threat… people are talking modular quite heavily. You have to build a very big factory to compete, or to take, significant market share away from us. I don't know how many modular there will be. But I imagine it's no more than, no more than , if they performed maybe 10,000. 10,000 out of 300,000 is quite a small patch	I12_I014	WoodAlpha
Being Disrupted	What we do is high-tech, playing not only with printing, with robotics, but Internet of Things: parametric modelling and then we change actually the entire supply chain.	I13_I015	3DBeta
Being Disrupted	They have a hard time in those big companies to actually develop new technology for real, and actually pushing. So, they set up this Moonshot Factory	I15_I017	3DAlpha
Being Disrupted	Innovation in our marketplace is encouraged but normally priced out, because everything is price driven	I16_I018	WoodBeta
Being Disrupted	I think it'll be an innovator. I mean there's companies like L&G that entered the marketplace, so that's a real departure. An insurance group recognising that this demand for housing, putting together a completely new team, new innovation.	I16_I018	WoodBeta
Being Disrupted Christensen	Our business model was to move ourselves from the low end, to move into middle end, upper end. They're	I17_I019	WoodGamma

	still going to need things and they carry on spending. When it becomes a commodity, you're in trouble. And that's what happened to us. The price got driven down, so when they took us out, they were taking us out of the market to maintain their market share.		
Being Disrupted	We should be all going to a digital construction process	I18_I020	3DZeta
Being Disrupted	The big builders have all done trials with the modular build. They all have, but I haven't seen, not aware of any that have really gone, “okay now we have this modular build product” that they introduced somewhere else. I just don't see that.	I19_I022	ConstructAlpha
Being Disrupted	We're trying to force through a significant change in the house building market in terms of the cost of building…to force through innovation in construction, innovation in pricing and all of that so that we can get to kind of fairly strict price points.	I24_I032	SovFund
Being Disrupted	Disruption will start with the incumbents in places like Nigeria, India, China is because it's the State that's going to do it for housing is that they, somebody needs to say there's a hundred billion pounds. We're going to build for 100 billion. We're going to build 100 million houses	I30_I047	DoorsAlpha
Being Disrupted	Are there any disruptors? Well, look at one, this is how disruption is looking like. At least, I'm representing some of the disruptors out there…the construction industry is ripe for disruption by 3D printing companies	P06_I049	3DAlpha
Being Disrupted	If you go to do digital transformation, you need to think big, and keep thinking big	P10_I051	SoftGamma
BIM	I would say that BIM’s definitely an innovation. is it going to be a market generating one? Yes, to a degree.	I08_I010	SoftAlpha
BIM	BIM is not a technology, BIM’s a theory, it's a methodology if you like.	I08_I010	SoftAlpha
BIM	All the tools are almost ready to be fully-fledged BIM, but it's just not being put together in the right ways, yet	I15_I017	3DAlpha
BIM	We're looking at BIM systems at the centrepiece…and we're going to build our systems around the 3D model, open-source model.	I18_I020	3DZeta
BIM	You can't sort of BIM it part way through, you've got to be right on it at inception really.	I19_I023	ConstructAlpha
BIM	We take the digital drawing, put it into print, it will print whatever, which to print. another interesting part is that when we do 3D printing, we go directly from the BIM software to the construction, which means we have a digital bridge from our design software into our actual physical objects or house, wall or whatever	P02_I017	3DAlpha
BIM	Software BIM development has not so far been very widespread	P02_I017	3DAlpha
BIM	If you look at other sectors, automotive, aerospace, mechanical engineering, they sorted out their 3D model formats back in the 80s. And everyone drove forward with that pushed all the way up supply chain free tools for people to use them, without paying exorbitant licenses. The upshot is, once we figure this out in construction, get our heads together and actually come up with a standard that works for	P03_I048	SoftBeta

	everyone, all this data, nicely drops into systems such as SoftAlpha, because suddenly all that data is readily available in the format and the aggregated, stored and then go into products		
BIM	In line with the BIM thinking, this is all digital, we need some digital input to actually get a physical product…It starts with that we have an input file. And that can come from your Autodesk or can be a scan file that you scan something...put that into your computer and to your programme…all based on digital data, then transformed into a physical product or product. And this of course, can also be combined with the visualisation of planned new building.	P06_I049	3DAlpha
Business Model Innovation	An open BIM compliant computer aided design platform that Joe Bloggs builder could log into to knowing that there's a knowledge base of information in there that would enable him to accurately create a model of whatever it was that he wants to build…And he'd know that if he use that piece of technology, it would have something which would give him everything that he needed. Like in terms of all the structural and architectural tolerance has built into it and also it would, the cost of building that particular item. I think that would be a real innovation in terms of the mass construction market because the trouble with the CAD technologies has always been historically unbelievably expensive So that would be a significant innovation to the smaller medium size business market…for businesses that are up to about 50 million a year in turnover…If those people, then had an automatic link from that model into an offsite manufacturing and then then from thing got delivered to site so they can just assemble it. That is innovation and true innovation in my opinion within the construction industry, which could be unbelievably disruptive	I08_I010	SoftAlpha
Business Model Innovation	The real practical barriers to innovation, is the mindset and the business model.	I08_I010	SoftAlpha
Business Model Innovation	I think that still holds true and the people who will win will be those who come up with the best innovations in critically beneficial areas for additive and then they all get so good at it that other people find it hard to compete.	I10_I012	3DPAM
Business Model Innovation	Everybody's looking at it from the technology standpoint of just a machine, and I'm looking at it in a broader scope, to say, "We need to change the business model" and the machines, and materials that we use, and the supply chain, and the process that we get the materials to the job site, that all needs to integrate much better than it has in the past. And that's what I'm working on. I mean, to me, that's going to be the technology changer, is the whole business model.	I18_I020	3DZeta
Business Model Innovation	It's not that far off, but it's centred around the BIM model. The BIM model is basically you've got a single source of model, single source of document, single source of tasks, high accessibility from contractors, the building owners, the engineers, to the project	I18_I020	3DZeta

	managers, to architects: all that look at that digital picture…We're working on this right now.		
Business Model Innovation	I think for all of us who are practitioners in the market, and I can see that focus is beginning to change in some sense towards where can we find innovative solutions towards kind of unlocking the restrictions around the demands and pretty much like a closed off market.	I24_I032	SovFund
Business Model Innovation	With funding comes better technology. And that's what I said before, if more funding was being provided, then the technology will be developed, and it will outcompete the conventional construction industry. And these guys are actually showing exactly that.	P08_I049	3DAlpha
Business Model Innovation	We want to make the process, particularly construction easier and safer. The other part was to streamline and speed up the process…if you get to a production system going you get a much more manufacturing approach Once we standardise that triangle. Can connect so each, all the suppliers can connect, you don't have to design with a particular manufacturer in mind, you can open up to the entire market.	P09_I050	ConConsult
Business Model Innovation	Three really simple steps to be able to build that innovative organisation, that organisation that can face that disruption that is going to happen every day. The first thing you need to think about is modernizing…*(secondly)* I am less interested in the amount of stuff that you build; I am more interested in the amount of stuff that you throw away. Because unless you are throwing lots of stuff away, you are not moving fast enough…*(thirdly)* the culture that you build inside your organisation. And that is an innovative culture that exists everywhere. That is democratised…The inclusiveness of your innovation and culture will also help you navigate those difficult moments.	P10_I051	SoftGamma
Business Model Innovation	To say this industry is going to be defined by a particular product in 5 years' time is probably less helpful in your journey towards building an innovative organisation. The nature of the world around you at the moment is that you might set off on that direction there. But someone's going to disrupt you, someone's going to come in completely tangentially and take you somewhere else. If you've invested all of your capability and pushing towards that particular technology or product, you're going to be less able to be able to respond to the disruption that comes in from over here.	P10_I051	SoftGamma
Is it Innovation	I made this bold statement that an innovation cannot be an innovation unless it adds value over a medium to long term to the person that's on the receiving end of the innovation. It's not just to me about innovation, it's about the sustainability and the value that that's really at the end, you know, not just to the individual, but socially and economically beyond the pure putting a roof over somebody's head	I08_I010	SoftAlpha
Is it Innovation	I don't think BIM is an innovation. BIM is just a methodology that people should have been using it	I08_I010	SoftAlpha

	and actually they know they should have been using it for the last 50 years because of cost and laziness 3D printing is a real innovation because we only ever been able to print things historically and now, we can 3D print.		
Is it Innovation	I think we need to be careful with innovation, moving product forward, making changes for the sake of making changes. Because what we do at the moment does work. If cost is a driver, that's brilliant. If there's a need for quick housing I understand that. But you've got to question it over here. You've got to question how the innovation's going to fit in. There has to be a win-win somewhere	I17_I019	WoodGamma
Productivity	I think the big challenge for everybody in the construction sector is the rate of failure.	I30_I047	DoorsAlpha
Productivity	In construction, we have actually seen all steady or slightly decrease in productivity. So, it means that, that if we look at the reasons for this, it's mainly that we have had close to no automation within this field. But we've had a lot of safety regulation being put on top of this field at the same time	P01_I017	3DAlpha
Productivity	We can actually increase the productivity already with this technology, Faster completion times, reduction of waste in terms of you can because the design is digital, you can choose where you want to put your materials … to make it more efficient.	P02_I017	3DAlpha
Productivity	We have seen commercial construction industry lately there's been no productivity gains. All research showing the last 30 years, you guys have not increased productivity, Different from industry, where your productivity gains every year of 1 to 2%, You have reached the end of the technologies that you are applying right now. Now here comes our technology. We will become competitive; this will be a better technology and we will outcompete parts of the conventional industry.	P08_I049	3DAlpha
Productivity	We think there's a new way and a different way of thinking to try and look at productivity, which different way new measures of performance how we do things, quite critical in my view of the way in procuring, different minds from clients and has challenges and look beyond the perceived constraints of what we have to work with in construction. It is the design and the procurement in manufacture.	P09_I050	ConConsult
Vision	I'm really, really passionate about enabling the construction industry that we serve. Enabling the level of disruption. In the way they think about things and the way they do things. And we are obviously trying to spread our own footprint out beyond what we've been classically known as doing. We're early in that early in that curve to me we are right at the foot of that innovation curve before the big thing. Obviously, we're all hopeful that the big growth phase will come.	I08_I010	SoftAlpha
Vision	My biggest passion is development in a broader sense of word, of the word. So that means personal development, development in the team. Being an entrepreneur, development of an organisation, as well technical development	I13_I015	3DBeta

Vision	It's not only about the printer, it's the entire concept of design, engineering, the hardware, the OEM, the software, and the material of the printing technology…We are a technology provider…it's about concept. It's not about printing. People want to have a house being build fast and affordable…from that perspective, we started to develop the technology.	I13_I015	3DBeta
Vision	I want to change the way we develop land and communities, not just build houses. Because I'm really looking at this is to be the most customer-friendly construction entity out there.	I18_I020	3DZeta
Vision	We intend to build 500,000 homes in a very short period of time.	I24_I032	SovFund

Table 9.14 Ecosystem Strategy Interview Quotes

Construct	**Illustrative Quotes**	**Interview/ Participant**	**Company**
Central or Periphery	We have the right stakeholders in the industry to help shape it…but I think it would be foolish to believe that we're dead centre.	I02_I002	SoftAlpha
Central or Periphery	I think it's farfetched to think that we're the centre of the construction universe…it's such a wide area. We are pretty key to a fair chunk of the UK construction.	I03_I004	SoftAlpha
Central or Periphery	We're one of the maybe half a dozen firms sit like we do. we're carrying out as industry association some fire tests …and we are one of the people to be asked to assist in it. There were many people that wouldn't be asked to assist in it…but we are one of the people that would sit at the centre there and well connected there with our competitors. And all the technical work around it really, the timber frame centralises and clusters around ourselves.	I12_I014	WoodAlpha
Central or Periphery	Currently, yes, I would say 3DBeta, 3DRho, and our company is the three most interesting	I15_I017	3DAlpha
Central or Periphery	I don't think our brand is big enough and our differentiation isn't great enough, to what they are now We'd like to be. But that component of disruption and innovation, we're not	I30_I047	DoorsAlpha
Collaboration	We are being very collaborative doing that way. The risk of course is, is make sure you don't pick somebody who is too inward looking. Or backward looking.	I02_I002	SoftAlpha
Collaboration	I think cooperation and collaboration partnerships is an opportunity at every stage in a business, but it then depends on whether your business and your competitors, are suited to that type of behaviour.	I10_I012	3DPAM
Collaboration	There were opportunities for us to cooperate to develop the market, and they weren't taken…Why didn't they cooperate? Probably because they were in the stronger position. They had multi-million government funding. We had nothing. So, we just had to scrap along and try and cooperate with whoever would talk to us to start with whereas they didn't need to cooperate because they had the funding and the financial strength to just go from the outset. Maybe that's what it was.	I10_I012	3DPAM

Collaboration	We are collaborating So we are developing technology and they are actually in the process of spreading it out…We tried to make these collaborations with many different companies in the industry.	I15_I017	3DAlpha
Collaboration	We used to be in a situation where nobody collaborated…what actually happened is people went down different routes trying to get to the same aim. We then started creating technical committees. And technical committees are great because people are not commercial. You'd have 12 guys sitting in a room and they'd come up with solutions and we then bring it back through the commercial people.	I16_I018	WoodBeta
Collaboration	There's a lot of cooperation between academia and business, which is really normal for Europe. But it's a really good way to push a new technology forward as well. It's very lacking in Asia in the US.	P02_I017	3DAlpha
Collaboration	Digital twin is more of a collaborative processing of people working together…This is the vision This is the ethos, probably a few years away from having fully operational digital twins. But that's not to say that we can't start working towards them now.	P03_I048	SoftBeta
Collaboration	Digital twins, we bring several disciplines together, we have disparate models, we've got architects, we've got architectural model, we've got structural engineers, we've got structural model, mechanical, electrical plumbing, services that actually make the building tick, and these all come together.	P03_I048	SoftBeta
Collaboration	We created a consortium…And actually, I think despite whatever comes out is one thing that will stand out is two alleged competitors opening up and collaborating and sharing information…because they saw the advantages of what they could do with this.	P09_I050	ConConsult
Keystone	It's the government, ... they are trying to do it ... they're trying to work with as many states that are ready. States who will provide land for them and all of that. It's a project from the centre, but they are working with private developers at different state levels	I04_I006	AfriHouse
Keystone	Microsoft are absolutely key starting point for the ecosystem. when you move beyond, the providers of the raw technology, then obviously significant part of your ecosystem. If business partners, that you need to provide, the complimentary technologies that are required to deliver your type of solution to the market	I08_I010	SoftAlpha
Keystone	Autodesk which are always like, a dominant supplier in the industry. So, they're almost there on that really	I12_I014	WoodAlpha
Keystone	I think AutoDesk tries to be, but they, they are not taking the right steps, or maybe just not fast enough. I think that they try to be the market leader in such a way that they are more of a monopoly Most of the software that they've just bought the companies who developed it and tried to standardise how their performance work and so on, but they still don't their software don't speak to each other. It's a huge task	I15_I017	3DAlpha
Keystone	I don't think there are (in the construction industry)… I think, there is in the house building sector because that's consolidated…There's the top eight that really	I30_I047	DoorsAlpha

	controlling that whole market. There isn't (a keystone), there are key players		
Open/Closed Innovation	I think historically we've been closed, but I think that has been changing. So, I think what we've recognised is we don't have to do everything in-house… So, it has changed. But I think that's historically, that's changed, in terms of not only that thought process but moving away from a monolithic piece of software to a suite of applications that fit together.	I02_I002	SoftAlpha
Open/Closed Innovation	I think our approach has been very open until now, because we have learned a lot from the …other companies and universities. And we have somewhat tried to share that as much as possible. That's why I049 is doing all these conferences as well.	I05_I007	3DAlpha
Open/Closed Innovation	Open vs. closed systems, because a lot of it's down to fear or lack of imagination. Now maybe I'm a little bit hard-nosed on this one…by being perhaps a little scathing by suggesting its lack of imagination.	I10_I012	3DPAM
Open/Closed Innovation	We have this, like, a learning community. We share all the new things. Based on that, this gets better and better. We're open, but within our own community. What we do is we play the game risk, so within every country, we have either one or two partners. That means we have a partnership agreement, and then they purchase printer	I13_I015	3DBeta
Open/Closed Innovation	It's getting there but the danger is, we're all trying to innovate ourselves when we should be doing more open construction.	I16_I018	WoodBeta
Stakeholders & Partners	And now we're doing another one, together with I think 14 other companies, it's really big…we were just seeking the investment at the fund. And then we partner up with a construction…And some material companies, to know about materials.	I05_I007	3DAlpha
Stakeholders & Partners	I think that the golden rule…something in it for both partners, but there's something that's different. One might be creating the market, the other might be creating technology whereby together they're worth a lot more than, than what they can do separately. Document it and make sure that each side very clearly understands what they're putting into it and what they're supposed to be getting out of it… and a shared vision, so you need a partner that embraces whatever vision you've got so if things are difficult and challenging they would push that extra mile to get there.	I11_I013	UniAlpha
Stakeholders & Partners	It was not about selling the printers, but more like understanding the problems of your potential partners. Based on that, we entered the first partnerships	I13_I015	3DBeta
Stakeholders & Partners	We have 127 developers. We are signing up large scale developments with large scale developers with experience and track record for executing large scale development…the second challenge is the continuous engagement route, which is basically one off relationships with small to medium size development companies	I24_I032	SovFund
Stakeholders & Partners	We have a large international and national network of interests in construction. We actually have two universities close who have been working with this.	P02_I017	3DAlpha

	We have very soon 3 universities, so they are taking research from the universities and helping companies actually use it out there in the commercial world.		
Stakeholders & Partners	We need money…the technology, this emerging industry that we are speaking about needs more resources to develop faster. We need cooperation with academia, …also leading corporations to the conventional suppliers, the materials suppliers and normal technology suppliers, the leasing guys, the construction companies, we all need to get involved with we have to move this thing further is also began but we need more.	P07_I049	3DAlpha