Sustained competitive advantage using Industry 4.0 strategies: A case of UK infrastructure sector

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This thesis is submitted in line with fulfilling the requirements for the degree of Doctoral of Philosophy (PhD) for the University of Wolverhampton.

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This work and any outputs have not been previously presented in any form to the university or any other society for evaluation, publication, or any other intention (unless specified otherwise). Apart from any references, bibliographies, and cited work, I can verify that the rational output and contents of this work are results of my own efforts and no other individuals.

Signature:

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DEDICATION

This thesis is dedicated to my family and friends.

RESEARCH OUTPUT

JOURNAL PAPERS

1. Jallow, H., Renukappa, S. Suresh, S. and Rahimian, F., (2022), **Artificial Intelligence and the UK Construction Industry – Empirical Study**, Engineering Management Journal, Taylor and Francis Publications.

2. Jallow, H., Renukappa, S. and Suresh, S. (2021), **The impact of COVID-19 outbreak on United Kingdom infrastructure sector**, Smart and Sustainable Built Environment, Vol. 10 No. 4, pp. 581-593. https://doi.org/10.1108/SASBE-05-2020-0068.

3. Suresh, S., Renukappa, S., Abdul-Aziz, A. R., Paloo, Y., and Jallow, H., (2020) **Developments in the United Kingdom Road transport from a smart cities perspective**, Engineering, Construction and Architectural Management (ECAM), Emerald publishing. DOI: 10.1108/ECAM-12-2019-0687.

4. Kamunda, A., Renukappa, S., Suresh, S., and Jallow, H., (2020) **BIM in the Water Industry: Addressing Challenges to improve the project delivery process**, Engineering, Construction and Architectural Management (ECAM), Special issue: Construction 4.0, Emerald publishing, 28(2), pp. 510-529, DOI: 10.1108/ECAM-122019-0692.

5. Suresh, S., Renukappa, S., Jallow, H., and Alneyadi, A., (2018) **Managing knowledge in a building information modelling context: a case study,** International Journal of Knowledge Engineering (IJKE), Vol. 10, No. 1, pp. 25–35.

CONFERENCE PAPERS

6. Jallow, H., Renukappa, S., and Suresh, S. (2023). **Industry 4.0 Strategies adoption in the UK Infrastructure Sector.** Festival of Research, 3 and 4 May 2023, University of Wolverhampton, Faculty of Science and Engineering (FSE) Research Conference ISSN 2634-2014, United Kingdom.

7. Jallow, H., Renukappa, S., and Suresh, S., (2022) **Business model innovation for Industry 4.0 agenda**, Business Model Conference 2022, IAE University School of Management, the 22nd and 23rd of June, Lille, France.

8. Jallow, H., Renukappa, S., and Suresh, S., (2022) **Industry 4.0 application adoption and implementation in UK infrastructure sector: Change management perspective**, Reimagining business, and management as a force for good, 35th British Academy of

Management Conference, 31st August - 2nd September, Alliance Manchester Business School, University of Manchester, Manchester, United Kingdom.

9. Jallow, H., Renukappa, S., Suresh, S., and Al Nabt., S., (2021) **Managing COVID-19 related knowledge in the UK Infrastructure sector**, 22nd European Conference on Knowledge Management 3–4 September 2021, Coventry University, Coventry, United Kingdom.
10. Jallow, H., Renukappa, S., and Suresh, S., (2020) **The role of Artificial Intelligence in Knowledge Management: The case of UK construction industry**, 21st European Conference on Knowledge Management 3–4 September 2020, Coventry University, Coventry, United Kingdom.
11. Jallow, H., Renukappa, S., and Suresh, S., (2020) **Industry 4.0 applications relationship to Knowledge Management**, 3rd International Conference on Knowledge Management Systems (ICKMS2020), May 15-17, 2020, at the University of Hawaii at Hilo, Hawaii, USA.
12. Jallow, H., Renukappa, S., Suresh, S., and Alneyadi, A., (2019) **Embedding Industry 4.0 Strategies within the UK Construction Industry**, International Conference on Innovation, Technology, Enterprise, and Entrepreneurship (ICITEE), 24 – 25 November 2019, Bahrain.
13. Jallow, H., Renukappa, S., Suresh, S., and Alneyadi, A., (2019) **Implementation of Building Information Modelling in the UK infrastructure sector – A case study,** 36th CIB W78 2018 Conference ICT in Design, Construction and Management in Architecture, Engineering, Construction and Operations (AECO), 17 – 21st September 2019, Northumbria University at Newcastle, United Kingdom.
14. Jallow, H., Renukappa, S., Suresh, S., and Alneyadi, A., (2019) **Strategies for Knowledge Management in the UK Construction Industry: Benefits and Challenges**, 20th European Conference on Knowledge Management, 5–6 September 2019, Universidade Europeia de Lisboa, Lisbon, Portugal.
15. Jallow, H., Renukappa, S., and Alneyadi, A., (2019) **The Concept of Smart Motorways in United Kingdom**, the 3rd International Conference on Smart Grid and Smart Cities (ICSGSC 2019), June 25-28, 2019, at University of California, Berkeley, USA.

16. Jallow, H., Renukappa, S., Suresh, S., and Alneyadi, A., (2019) **Implementing a BIM collaborative workflow in the UK infrastructure sector**, 2nd International Conference on Knowledge Management Systems (ICKMS2019), April 6-8, 2019, at University of Houston, Texas, USA.
17. Jallow, H., Renukappa, S., Suresh, S., and Alneyadi, A., (2018) **BIM Adoption in the Infrastructure sector – A case study**, 35th CIB W78 2018 Conference: IT in Design, Construction, and Management Chicago, 01 - 03 October 2018, Illinois, United States.
18. Jallow, H., Renukappa, S., Suresh, S., and Alneyadi, A., (2018) **Uses of 3D design and stimulation within UK infrastructure sector – A case study**, IFIP 15th International Conference on Product Lifecycle Management, 1-4 July 2018, Torino, Italy.
19. Suresh, S., Renukappa, S., Jallow, H., and Alneyadi, A., (2018) **Managing knowledge in a building information modelling context: a case study**, International Conference on Knowledge Management Systems (ICKMS2018), April 9-11, 2018, at Florida Polytechnic University, Florida, USA.
20. Jallow, H., Renukappa, S., Suresh, S., and Alneyadi, A., (2017) **Building Information Model for Construction management and planning**, International Conference on Sustainable Futures (ICSF) 26 – 27 November 2017, Bahrain.
21. Jallow, H., Renukappa, S., Suresh, S., and Alneyadi, A., (2017) **Building Information Model for infrastructure: challenges and benefits**, the Ninth International Conference on Construction in the 21st Century (CITC-9) "Revolutionizing the Architecture, Engineering and Construction Industry through Leadership, Collaboration and Technology", March 5th-7th, 2017, Dubai, United Arab Emirates.

POLICY PAPERS

22. Jallow, H., Renukappa, S., Suresh, S., and Nartey, J., (2021) **Governance impact on CO2 emission in the infrastructure sector (NZG0035)**, written evidence, Net Zero Governance, Business, Energy and Industrial Strategy Committee, U.K Parliament. https://committees.parliament.uk/writtenevidence/38340/pdf/.
23. Suresh, S., Renukappa, S., Abdalla, W., Erriadi, W., Jallow, H., Khan, A., Shetty, N, and Al-Janabi, R., (2020) **The burden of childcare/housework responsibilities during**

COVID-19 and the potential impact on working mothers’ productivity and wellbeing, women and work, Edited by All Party Parliamentary Group.

24. Jallow, H., Renukappa, S., Suresh, S., and Shetty, N., (2020) **Effect of COVID-19 crisis on women employees in the construction industry (COV0174)**, written evidence, The impact of coronavirus on businesses and workers, Business, Energy and Industrial Strategy Committee, U.K Parliament. https://committees.parliament.uk/writtenevidence/8648/pdf/
25. Jallow, H., Renukappa, S., and Suresh, S., (2020) **Adapting to COVID-19 crisis in the UK infrastructure sector (COV0168)**, written evidence, The impact of coronavirus on businesses and workers, Business, Energy and Industrial Strategy Committee, U.K Parliament. https://committees.parliament.uk/writtenevidence/7742/pdf/.

BOOK CHAPTER

26. Jallow H., Renukappa S., Suresh S., and Alneyadi A. (2021) **Building Information Modelling in Transport Infrastructure Sector**. In: Ahmed S.M., Hampton P., Azhar S., D. Saul A. (eds) Collaboration and Integration in Construction, Engineering, Management and Technology. Advances in Science, Technology and Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham. https://doi.org/10.1007/978-3-030-48465-1_12.

ABSTRACT

Globally, technological development is growing rapidly where nations around the world are becoming more digital and data driven to shift into the fourth industrial revolution (Industry 4.0). The United Kingdom is on the route to follow these footsteps as their government have set plans to digitise and automate industries to achieve the goal of better efficiency and productivity thus, improving the economy. Despite the efforts from the UK Government enforcing a mandate in a minimum Level 2 BIM (Building Information Model) for all public sector projects over the contract is over 12 months and worth £10,000,000 or more, organisations within the infrastructure sector are still witnessing challenges in incorporating industry 4.0 agenda within their projects and processes. Additionally, there is a scarcity of literature and research on the implementation of industry 4.0 strategies within the UK infrastructure sector to increase productivity and improve organisations competitiveness. Consequently, this research aims to conduct an evaluation of the UK infrastructure sector and their implementation of industry 4.0 strategies to improve processes and competitiveness. This research uses a qualitative approach, and 21 interviews were conducted from five large UK infrastructure sector organisations and eight small to medium sized organisations within the sector. Purposive sampling was adopted in the early stages of research which was turned into snowball sampling further in the research. The data collection method adopted was semi structured interviews where the interviews data were analysed through thematic analysis to gain a wider perspective of the interview data. To accomplish the aim of the research, the following systematic approaches were adopted; TISM (Total Interpretive Structural Model), Fuzzy MICMAC (Fuzzy Matrice d'Impacts Croises-Multiplication Applique an Classment), GTMA (Graph Theoretic and matrix Approach), and the Maturity Model. This research outputs a framework and a developed readiness tool. The results have suggested that the infrastructure sector have identified four key change processes that are vital for industry 4.0 strategies: People, Processes, Strategies, and Tools/Technology. The UK infrastructure sector is behind in complying with the laws set by the UK government despite organisations providing the required tools for implementation. It has been found that competitiveness has been one of the main key drivers for organisations implementing industry 4.0 initiatives. Software and hardware challenges were highlighted as the main challenges for industry 4.0 initiatives implementation within the infrastructure sector. The results of this research study highlight useful intuitions that would be beneficial to the UK infrastructure sector and the decision makers within their organisations to adopt and implement industry 4.0 initiatives to provide value to organisations productivity and efficiency.

CHAPTER 1: INTRODUCTION TO THE STUDY

1.1 BACKGROUND OF STUDY

The UK construction infrastructure sector takes an active role in the UK economy (HM Treasury, 2022), high-quality infrastructure with high performance can improve the quality of life as well as boost economic growth. Infrastructure investment can provide a strong economic encouragement that can assist in the growth of a country, investing 1% of GDP can increase production by 0.4% within a year and can increase up to 1.5% within four years of the investment (Eurydice Fotopoulou, 2022).

The Infrastructure Sector faces a significant amount of pressure from the UK government to eliminate the factors that can affect construction and asset management (Infrastructure and Projects Authority, 2021), this includes the reduction of project costs while improving efficiency and achieving sustainable construction.

Within an organisation on a project, the activities are undertaken by different stakeholders which include the client, contractors, engineers, designers, and sub-contractors just to mention a few and these individual teams mostly decide on their disciplines without the consideration of the other disciplines which can create issues. These issues being created can lead to delays in the project which increases the time and impacts costs as more resources must be paid for to complete the project and influence the productivity of the organisation. Eagan has noted how within an organisation, each of the parties involved act without trusting other parties which effectively passes down the risks to the following supply chain and minimise their exposure (Egan, 1998). These conflicts eventually lead to increased costs while reducing efficiency and productivity.

There has been a major focus on the improvement of productivity in construction using the Internet of Things (IoT) and Information and Communication Technology (ICT) (Scherpenisse, 2012), these concepts have been proven to reduce the time of processing data while enhancing the communication between the parties within the organisation overall improving productivity. There has been plentiful research on modern technologies and processes such as the Building Information Model (BIM) which has indicated a promising method of positively influencing cost issues by taking advantage of the design of the constructions (Jian et. al, 2014). Not only can the Building Information Model be used for buildings, but it can also be used within the infrastructure sector for assets that are linear and not high-rise, i.e., roads. The construction industry is an enabling sector as it includes a great deal of different sub-sectors in which an investment in just one sector can surely create a better economy providing jobs as well as improving the state of a country, delivering around £370 billion GVA to the UK economy back in 2016 (Infrastructure and Projects Authority, 2021). The UK government has invested a great amount into the UK infrastructure over the next couple of years, with this investment, standards were set by the Government which led to the introduction of the Building Information Model (HM Treasury, 2022) plus more strategic automated processes within the industry.

Industry 4.0 is the fourth industrial revolution that involves the automation and digitisation of the manufacturing industry. The Industrial Revolution began in 1781, this had a slow start, however over time it has massively changed and impacted how products are produced, communication, the way we live, and many more day-to-day processes (McKinsey and Company, 2022). The UK construction industry is undergoing significant changes since the 18th century, the manufacturing industry which includes the construction industry saw its first industrial revolution with the creation of the steam engine (Bank of England, 2020).

Between 1970 and 1914, the world saw the 2nd industrial revolution coming up. The first industrial revolution showed growth in iron, railroads, and textile industries while the second industrial revolution was the growth of electricity, steel, and petroleum (Longley, 2021). During this time, a lot of changes were witnessed the biggest change in the construction industry being the replacement of iron to steel within construction. Between 1870 and 1881, Britain became the first country to install a public power station (Longley, 2021), this was just the start of the electrical inventions and improvements which changed how people worked and lived. In 1879, electricity started being used for transportation and the first railroad was created in Berlin, Germany, the following year saw electric cars were introduced which replaced horse carriages in most major European cities (Vale, 2016).

The 3rd industrial revolution came across around 1969 within the second half of the 20th century, this revolution was the start of the rise of electronics, telecommunications, and computers which opened opportunities in the exploration of space and research (Pouspourika, 2019). This revolution saw the computerisation of the entire economy which introduced a change in the way we worked, produced, and entertained allowing for a change in the management of different processes (Roberts, 2015). As mentioned, the introduction of the third industrial revolution provided technological advances which meant that the reliance on labour as the only means of production was majorly reduced.

The concept of "Industry 4.0" refers to the digitised way of working within the industrial and manufacturing industries to increase value creation (Ghobakhloo, 2018). Industry 4.0 is considered as the ability to connect humans, machines, objects, and information and communication technology (ICT) intelligently which results in future value creation. Enabling this interaction allows real-time intelligence to be utilised in creating value. Industry 4.0 is assumed to produce various opportunities in terms of improved quality and efficiency to provide competitiveness within companies (Muller and Voigt, 2018). This industrial revolution is not only changing the manufacturing industry but the way we as humans live, work, and relate to one another where physical, digital, and biological worlds are being merged (World Economic Forum, 2020).

Industry 4.0 can provide a lot of opportunities for companies in various fields, however for companies to gain full benefit from Industry 4.0 solutions, the implementation of these technologies needs to be done in a manner where the full benefits are gained by the companies. There is little experience within the construction industry as to how to implement Industry 4.0 practices, in addition given its complex nature implementation strategies will need to be tailored to individual organisations and specific technologies associated with the implementation. The literature reviewed has only provided cooperative practices so far in terms of Industry 4.0 where it is difficult to understand the best way to implement this industrial revolution.

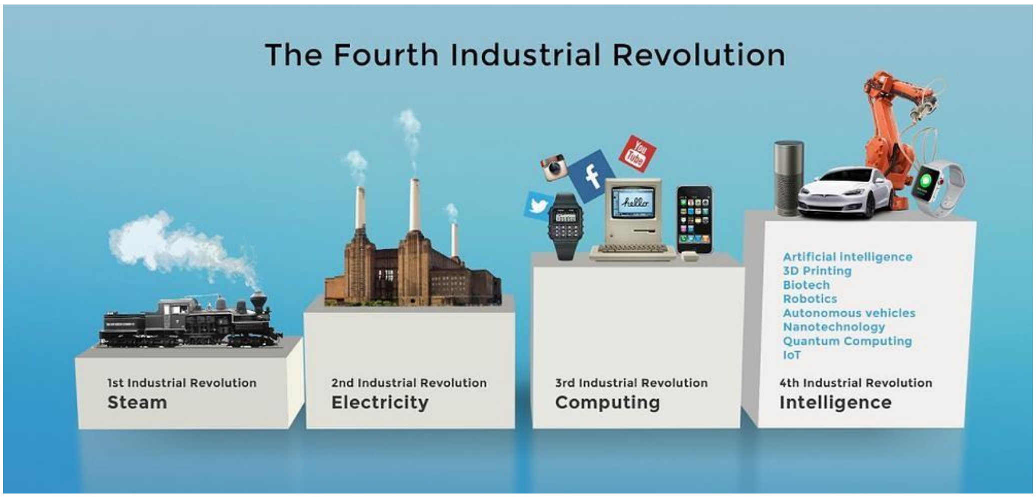


Figure 1.1: Industrial Revolution Evolution

Source: Zaman (2020)

One of the industry 4.0 technologies is the Building Information Model which has grabbed a lot of attention over the past 10-15 years. As of April 2016, the UK government has mandated the use of Level 2 BIM for all public sector construction projects (Infrastructure and Projects Authority, 2021), the main reason behind this mandate was the BIM can transform the construction industry leading to a new revolution by enhancing the project processes and with the use of these technologies and processes the whole asset life cycle can be better. Usually, we can hear BIM being described as a 3D model, however, this BIM is a process that allows project information to be structured, organised, and easily exchangeable (Eastman, 2011). The provision of information that is structured leads to effective communication and collaboration between the different parties throughout the project's lifecycle (Smith, 2009). This new approach provides the construction sector with confidence in a new process that can assist in achieving a high level of efficiency and productivity for the sector.

The BIM implementation process is one with which organisations struggle, according to the NBS National BIM Report 2020, (NBS, 2020), there is awareness of BIM in the UK especially after it was mandated. Based on the latest available National BIM Report 2020, 62% of the people/companies interviewed were aware of BIM and are currently using it, whereas only 3% were neither aware nor using BIM. BIM is thought of to transform the whole construction industry revolutionising construction projects (NBS, 2020). Despite the positive outcomes which have been highlighted from the use of BIM, there is still 35% of practices are aware of BIM however they are not using BIM as there are barriers when adopting the process (NBS, 2020). Contractors in the UK have a lack of drive to fully implement BIM as it does require time and costs during its implementation stage which some contractors do not feel it is worth (PlanRadar, 2022) Contractors would essentially need clients to demand implementation which would motivate more construction companies to start implementing BIM, furthermore the main challenges that are usually identified while implementing BIM are at the organisations level, this shows the overall companies have to overcome the resistance in the implementation on BIM and barriers such as training can be executed easier with instruction coming from higher management within the organisation (PlanRadar, 2022).

Industrial revolutions have evolved over the years and while we are currently at the prime of the 5th Industrial Revolution in 2023, the construction sector is still in the process of fully immersing into the 4th Industrial Revolution. The infrastructure sector is behind compared to other sectors within construction. The UK government has been investing in infrastructure within the UK over the past decade to boost the economy and plan on ongoing development through 2030. This is why the UK government mandated the use of BIM in April 2016. Despite the mandate of one of Industry 4.0's technologies, BIM, which was enforced 7 years ago, the infrastructure sector organisations still lack an understanding of the BIM processes while other Industry 4.0 strategies are arising. Organisations are facing challenges in adopting these strategies which have been found to boost other sectors' production and efficiency massively. Additionally, the construction infrastructure sector has been assigned many jobs due to the National Infrastructure Delivery Plan produced by the UK government which makes it vital to construct these projects in the most efficient productive, and sustainable manner.

1.2 PROBLEM STATEMENT AND RESEARCH JUSTIFICATION

Infrastructure is the basic type of equipment and structures that are needed within the economy for it to function properly. For the past seven years, the production of infrastructure has been at a steady decrease (HM Treasury, 2022) which has taken a toll on the economy. The government has decided to invest in infrastructure for the next 20 years (HM Government, 2021) especially within the transport sector, however providing a fast and efficient production has always been a struggle. From collaboration to clashes during construction, costs of building infrastructure increase as the construction goes on and even after construction as maintenances are not very well organised. The stake market report published in 2012 has specified that construction clients have very little trust in digital advances and automated practices when compared to the contractors and consultants in the industry (PlanRadar, 2022). Clients in the UK are finding it difficult to put their full trust in the new strategies which include understanding its benefits (Finger and Montero, 2023), in addition to this the lack of knowledge on how Industry 4.0 strategies can benefit a project throughout its lifecycle and its expected value is a major issue.

The use of digitised processes and automation in the infrastructure transport sector is not clearly defined which is the reason why clients find it challenging to decide to invest in the use of advanced digital solutions as the benefits are not clear to them (Finger and Montero, 2023). The UK construction industry is still to accept these technologies which is the main barrier which is sourced from a lack of awareness of the possible benefits that can be gained, the lack of knowledge is also an issue as a massive amount of training of Industry 4.0 applications will be required throughout the industry (Franceschi, 2022). Eastman et al (Eastman, 2011) has argued in their number of publications on how automation and digitisation can benefit the infrastructure transport sector, however, these arguments are more project focused as the benefits shown are benefits to the project rather than the business of the client. In terms of the

Building Information Model which is one of the Industry 4.0 applications, the Plan Radar (PlanRadar, 2022) has linked the benefits gained from BIM to its capability and maturity level, however, this is not clearly defined which is why there is a lack of knowledge on what maturity level to implement to achieve maximum benefit from BIM for an organisation. This uncertainty would become clear if there were clear guidelines available for clients to follow to allow them to gain the benefits they require from BIM.

BIM as well as the newly developing Industry 4.0 applications such as Artificial Intelligence are new to the infrastructure sector, several organisations have been aware of some of these applications, however, they have been mainly popular in the Architecture and Mechanical industries over the past year. With the UK government mandate of Level 2 BIM with all public sector projects, the infrastructure sector is to use BIM within their projects. To enable this mandate to go forward, obtaining guidance will add clarification about what is required for the clients to achieve the maximum benefits from Industry 4.0 agenda in all the different areas of the project's lifecycle. Due to the lack of popularity within the infrastructure sector of industry 4.0 strategies, there needs to be a more defined way of adopting these strategies which involves understanding the challenges within the sector and where they derive from leading to how these challenges can be overcome.

1.3 RESEARCH AIMS AND OBJECTIVES

This research aim is to explore and evaluate the UK infrastructure sector and their implementation of industry 4.0 strategies and how the UK infrastructure sector improves organisations' competitiveness and introduces more efficient processes. Additionally, understanding the challenges that the infrastructure sector is having currently is an essential part of this research as it would help in knowing how using digitised and automated processes changes the difficulties making the industry better. The following objectives have been developed:

1) To explore the status of the UK infrastructure sector and industry 4.0 strategies.
2) To explore the outlook of industry 4.0 strategies in general and the UK infrastructure sector.
3) To investigate the key drivers for embracing Industry 4.0 strategies in the UK infrastructure sector.

4) To explore and understand the key Industry 4.0 strategies implemented in the infrastructure sector.
5) To investigate the challenges of adopting Industry 4.0 strategies in the infrastructure sector.
6) To investigate the key leading change strategies that have been adopted in the UK infrastructure sector to embrace Industry 4.0 concepts.
7) To explore the potential benefits of adopting Industry 4.0 strategies in the infrastructure sector.
8) To develop and evaluate the industry 4.0 business model framework.

1.4 RESEARCH QUESTIONS

Upon review of the background of the research, the justification of the research, and the aims and objectives developed for this study, the following research questions were developed:

1) What is the status of Industry 4.0 strategies in general within the infrastructure sector?
2) What are the key drivers that have fuelled the need for embracing Industry 4.0 agenda in your organisation?
3) What is the relationship between the key drivers?
4) What are the key ‘Industry 4.0 strategies that are currently being adopted within the infrastructure sector?
5) What is the current level of implementation of Industry 4.0 strategies within the infrastructure sector?
6) What are the main challenges the infrastructure sector faced organisations when implementing Industry 4.0 agenda?
7) What is the most influential challenge that the infrastructure sector face in implementing Industry 4.0 agenda?
8) What are the key change management strategies being implemented within organisations in the infrastructure sector to manage Industry 4.0 agenda issues?
9) What are the efforts that Industry 4.0 agenda has contributed to organisations within the infrastructure sector?
10) Is there a need for developing an innovative business model for adopting Industry 4.0 agenda within the infrastructure sector?

1.5 RESEARCH METHODOLOGY

The methodology of this research was undertaken through a pragmatic approach as the study is of a nature that has not been explored before. Secondary data was collected through a systematic literature review using the PICO model (See Chapter 4 for more details) and primary data was collected following a qualitative methodology to study the objectives of the research. A purposive sampling method was selected for this research and further in the research snowball sampling was adopted due to the sensitive nature of the study. Semi structured interviews were chosen as the data collection method. To achieve the objectives of the research developed, systematic approaches were used such as TISM (Total Interpretive Structural Modelling), GTMA (Graph theoretical Matrix Approach), and Fuzzy MICMAC. This then led to the development of a Framework which was mapped into a business model and a readiness tool was developed from the research findings. Table 1.1 demonstrated a summary of the methodology. The research questions were mapped to relate to the relevant research objectives and methodologies used which can be seen in Table 1.2.

Table 1.1: Research methodology summary

Classification of research	Exploratory study
Research Philosophy	Pragmatic approach
Research approach	Inductive Approach
Research Method	Qualitative approach
Research Strategy	Grounded theory
Collection of Data	Systematic literature review and Semi-structured interviews
Sampling methodology	Purposive Sampling and Snowball Sampling
Number of Participants	21
Data analysis	TISM, Fuzzy MICMAC, Thematic analysis, GTMA, Maturity model

Outputs of research	• Key drivers fuelling the drive to implement industry 4.0 initiatives in the UK infrastructure sector. • Key industry 4.0 initiatives that have been implemented in the UK infrastructure sector. • Key change management strategies implemented in the UK infrastructure sector to address industry 4.0 initiatives. • Key values gained through the implementation of industry 4.0 initiatives within the UK infrastructure sector. • Integrated Business model framework for implementing industry 4.0 initiative within the UK infrastructure sector. • An industry 4.0 readiness tool for implementing industry 4.0 strategies in the UK infrastructure sector.

1.6 CONTRIBUTION TO KNOWLEDGE

This study provides value to the UK infrastructure sector and its supply chain which includes all levels such as higher management, staff, policymakers, and the decision makers within organisations in the sector. The results will:

- Enhance knowledge and understanding within organisations of industry 4.0 concepts and innovation.
- Enhance the understanding of key drivers that pressure the UK infrastructure sector to implement industry 4.0 initiatives which can enable the higher management in organisations to understand the key drivers more leading to opportunities for efficient implementation and adoption.
- Aid the senior managers in organisations in the sector in building a plan of action for the adoption of Industry 4.0 initiatives.
- Enable change management strategies understanding for decision-makers in organisations for implementing Industry 4,0 initiatives.

- Allow organisations in the UK infrastructure sector to become more aware of the challenges barricading the implementation of Industry 4.0 initiatives.
- Allow organisations in the UK infrastructure sector to be enabled to assess their position and capabilities for the adoption of the initiatives with the use of the readiness tool and GTMA analysis.
- Increase knowledge on how Industry 4.0 initiatives impact social, environmental, and economic performance and their relationships with the initiatives.
- Guide senior leaders with the use of the framework developed to allow a better understanding of Industry 4.0 concepts while assisting the implementation, management, and control of these strategies and measuring performance.

Table 1.2: Relationship between the research objectives, research questions, analysis method, and chapters they were addressed.

Objectives		Research Questions	Analysis method	Chapter
To explore the outlook of industry 4.0 strategies in general and the UK infrastructure sector.	1	What is the current status of Industry 4.0 strategies in general within the infrastructure sector?	Systematic Literature Review	Chapter 2
To investigate the key drivers for embracing Industry 4.0 strategies in the UK infrastructure sector.	2	What are the key drivers that have fuelled the need for embracing Industry 4.0 agenda in your organisation?	Thematic Analysis	Chapter 5
	3	What is the relationship between the key drivers?	TISM (Total Interpretive Structural Model) and Fuzzy MICMAC	Chapter 5
To explore and understand the key Industry 4.0 strategies implemented in the infrastructure sector.	4	What are the key 'Industry 4.0 strategies' that are currently being adopted within the infrastructure sector?	Thematic Analysis	Chapter 6
	5	What is the current level of implementation of Industry 4.0 strategies within the infrastructure sector?	Capability Maturity Model	Chapter 6
To investigate the challenges of adopting Industry 4.0 strategies in the infrastructure sector.	6	What are the main challenges the infrastructure sector faced organisations when implementing Industry 4.0 agenda?	Thematic Analysis	Chapter 8
	7	What is the most influential challenge that the infrastructure sector face in implementing Industry 4.0 agenda?	GTMA (Graph Theoretic and Matrix Approach)	Chapter 8
To investigate the key leading change strategies that have been adopted in the UK infrastructure sector to embrace Industry 4.0 concepts.	8	What are the key change management strategies being implemented within organisations in the infrastructure sector to manage Industry 4.0 agenda issues?	McKinsey's 7-S Model	Chapter 7
To explore the potential benefits of adopting Industry 4.0 strategies in the infrastructure sector.	9	What are the efforts that Industry 4.0 agenda has contributed to organisations within the infrastructure sector?	Thematic Analysis and Triple Bottom Line (TBL)	Chapter 9
To develop and evaluate the Industry 4.0 business model framework	10	Is there a need for developing an innovative business model for adopting Industry 4.0 agenda within the infrastructure sector?	Systematic Literature Review and Thematic Analysis	Chapter 10

1.7 LIMITATIONS OF THE RESEARCH

This research has provided substantial insight into the topic, however, there are some limitations:

- Due to the research being exploratory, the presented results reflect only a portion of the population in the industry. Additionally, the research is limited to the UK infrastructure sector only, which means that the context may be limited in terms of generalisation. Despite this, the finding representing the UK is like that of other nations which could deem this research useful.
- This research focussed on the infrastructure sector, which means that the results may not be like that of other sectors and industries that partake in different activities.
- This research focuses on industry 4.0 initiatives, key drivers, challenges, change management strategies, and Value, these results are based on the thirteen organisations that took part in this study. Further studies to cover various organisations are recommended to gain more insight into the sector. Survey-style research is suggested to gather quantitative data where the ability to quantify the results This will allow the exploratory approach to be fulfilled where qualitative data has been collected and followed by quantitative.
- The readiness tool proposed has been assessed by experts within the sector however it has not been fully implemented by the organisations themselves.

1.8 STRUCTURE OF THESIS

The thesis structure follows a systematic approach where the reader can follow the flow of information. This allows the reader to gain an understanding of the research questions and their answers, additionally how the research objectives were achieved is easily identified through the flow. The thesis begins with an introduction in Chapter 1 and ends with Chapter 11 presenting the conclusions and recommendations.

Chapter 1

In this chapter, an overview of the research problem is discussed and includes the justification of the research. Aims and objectives are outlined and the research approach for this research is also discussed, and the methodology is briefly explained. An overview of the chapters is provided and briefly discussed.

Chapter 2

This chapter will critically go through the review of literature which are relevant to this study. These include issues in the UK infrastructure sector, IoT, industry 4.0, BIM implementation, Smart cities, and industry 4.0 strategies in terms of their benefits and requirements. This chapter also provides the theoretical background of the research study. The theories include the triple bottom line approach, institutional theory, and organisational change for Industry 4.0 which will be explored in this chapter.

Chapter 3

In this chapter, the research methodologies adopted to conduct this research are discussed and analysed. A qualitative approach was adopted for this research and justification for the methods chosen will be presented, followed by the data collection, and the method of analysis will be discussed. The chapter will highlight the challenges faced within the research and the steps that were taken to accomplish the research study. This chapter also highlights the rationale for the analysis methods used for each aspect of the results of this study.

Chapter 4

This chapter highlights the summary of the results and findings. The key drivers fuelling the need for industry 4.0 strategies is highlighted along with the industry 4.0 strategies that have been adopted within the UK infrastructure sector and the key change management strategies that's organisations within the sector have adopted to implement these strategies. The chapter then identifies the main challenges faced within the sector and concludes highlighting the contributions that industry 4.0 strategies have made to the organisation in the UK infrastructure sector.

Chapter 5

This chapter highlights the key drivers identified that have been noted to push organisations in adopting industry 4.0 initiatives in the UK infrastructure sector. The findings have been presented in three sections; the first section highlights the key drivers which have been identified in the study influencing industry 4.0 initiatives implementation through institutional theory. The following section demonstrates the use of TISM analysis which highlights the relationships between these key drivers. The final section outlines the driving and dependence powers of each key driver identified where the Fuzzy MICMAC was used to identify the driving impact. This chapter answers the second and third research questions and deals with the second research objectives.

Chapter 6

In this chapter, the key industry 4.0 strategies that have been implemented in the UK infrastructure sector are explored. The findings are split into two sections where the first section highlights the key industry 4.0 strategies adopted by organisations in the UK infrastructure sector. The second section presents a proposed maturity model to assess the organisation's level of implementation of industry 4.0 initiatives. This chapter answers the fourth and fifth research questions and deals with the third research objective.

Chapter 7

The following chapter will discuss and analyse, the key change management strategies that have been adopted in the UK infrastructure sector to deal with industry 4.0 strategies adoption. There are two sections to this chapter, the first section includes the discussion of the key change management strategies identified in the study. The second section maps the findings onto McKinsey's' 7-S model. This chapter answers research question six and deals with the fourth research objective.

Chapter 8

This chapter will include a discussion of the challenges faced in the UK infrastructure sector when implementing industry 4.0 initiatives. There are two main sections in this chapter, the first section highlights the key challenges that the UK infrastructure face. The second section utilises the GTMA to analyse the challenges and measure and compare the impact each challenge presents. This chapter answers research questions seven and eight and deals with the fifth research objective.

Chapter 9

In this chapter, the value provided by the implementation of Industry 4.0 initiatives in the UK infrastructure sector is explored. The findings were highlighted by using thematic analysis and were analysed using the tribble bottom line approach. This chapter answers research question nine and deals with the ninth research objective.

Chapter 10

This chapter presents the development of an integrated framework mapped into the VTDF business model for the implementation of Industry 4.0 initiatives and the readiness tool. These were developed based on the findings collected from previous chapters in this study.
This chapter answers research question ten and deals with the sixth research objective.

Chapter 11

This chapter provides a summary of the key findings of the study and offers future recommendations.

CHAPTER 2: CRITICAL REVIEW OF LITERATURE INDUSTRY 4.0 AND THE INFRASTRUCTURE SECTOR

2.1.INTRODUCTION

The purpose of this chapter is to study research conducted which are related to the research topic to understand the current knowledge of the study. The main areas that relate to this research are associated with the digitisation of the construction infrastructure sector, such as the transport infrastructure conditions in the UK, the implementation process of Industry 4.0 technologies, and the lack of understanding of the Industry 4.0 strategies within the Infrastructure Sector. The chapter includes the review of the UK's infrastructure sector development and the development of Industry 4.0 strategies. This chapter then highlights an overview of the key Industry 4.0 strategies within the literature in the UK infrastructure sector and what values are gained with organisations through Industry 4.0 strategies adoption. This chapter also addresses the change management considered within organisations to adopt industry 4.0 strategies and the UK infrastructure sector's challenges faced with Industry 4.0 strategies. The chapter then concludes and provides a summary.

2.2.DEFINITION OF INFRASTRUCTURE AND INDUSTRY 4.0

The term "infrastructure" is broadly used; hence it is worth exploring the different definitions of infrastructure to commence this investigation, Table 2.1 explore the different definitions of infrastructure.

Table 0.1: Definitions of Infrastructure

Source	Definition
The Investopedia team (2022)	Infrastructure is defined as the basic physical systems of a business, region, or nation and often involves the production of public goods or production processes.
Webster (2019); included three definitions of Infrastructure	“1: the system of public works of a country, state, or region also: the resources (such as personnel, buildings, or equipment) required for an activity. 2: the underlying foundation or basic framework (as of a system or organization) 3: the permanent installations required for military purposes”
Cambridge Dictionary (2019)	“The basic structure of an organization or system which is necessary for its operation, esp. public water, energy, and systems for communication and transport”

Infrastructure can be defined as the basic services and facilities that are required to operate a society (Cambridge Dictionary, 2019). The term infra stands for below which is because some of these services and facilities are underground such as gas, water, and communications supply systems. According to Craven (Craven, 2015), this infrastructure sector includes a variety of aspects such as roads, bridges, air control towers, dams and reservoirs, electrical power lines, schools, and hospitals, just to name a few.

Infrastructure can be defined in many different ways, however in the construction industry, it can be defined as physical assets, equipment, and facilities of unified systems along with the service providers and essential structures, organisation, business models, and also the rules and principles that are used to improve the living condition within specific sectors such as transport, energy and water supply and also waste management (Weber, 2010). There are two main forms of infrastructure when it comes to the construction industry which are as follows:

Economic infrastructure.

Economic infrastructure: also known as Technical Infrastructure, can be defined as infrastructure that supports the economy and usually gains pay from building it for example toll roads (Trimbath, 2011). This sector is made up of four different sub-sectors which are; Transport, which includes Land transport (roads and rail), Water (ports, inland waterways, and overseas waterways), Air/Aviation (Airports and air control), and Space (observation, research, and other services); Supply and Disposal, which consist of electricity (whether coal, gas nuclear or renewable), waste and water supplies; the final subsector is Communication which is in the form of high-speed internet, mobile network, fixed network, and satellite. We use these economic infrastructures in our everyday lives (Weber, 2010).

Social infrastructure

The social infrastructure sector is the infrastructure that includes assets and supports social services (Meeks, 2015). Social infrastructure assets include infrastructure to benefit Health such as medicine facilities and Ancillary infrastructure; Education for example schools, residential student accommodation, and libraries; Transport such as bus stations, park, and rides; Security, such as prisons, police stations, and defence mechanisms; and Civics and utilities, such as sports facilities, government facilities and water and waste treatment (Weber, 2010). For this study, Infrastructure refers to Economic Infrastructure.

The infrastructure sector takes an active part in the UK economy (Department for Business Innovation and Skill, 2013), which was represented in the government's growth review back in 2015 (UK Commission for Employment and Skills, 2016). During the last quarter of 2018, the UK has seen an increase of 0.28% (Jackson, et al., 2019) despite the increase in employment, productivity in the UK seems to not have the same effect on growth (Jackson, et al., 2019).

The construction industry has been identified as a primary influence on performance and productivity when good practices are used (Adetunji, et al., 2003), business practices within an organisation take a massive part in improving productivity within a project. Adopting the right business practices such as efficiently managing data and producing time and cost-saving processes can improve productivity while saving costs and enabling sustainable production.

Infrastructure consumes a great number of resources to build (Mandele, 2006), the production of Infrastructure typically involves a major amount of planning; time; and the participation of different stakeholders to ensure that the people involved have their needs and requirements prioritised, in addition maintaining the asset produces challenges to the asset managers which is why infrastructure organisations are changing their business processes to increase efficiency to improve their delivery services to clients and customers. The development of
Infrastructure has been a bit challenging over the years and so has the management processes post-production. There have been a few noted challenges as to why countries need infrastructure production which are summarised below:

- Economies need economic and social developments within the country to accommodate the growth of the population.
- Infrastructure is ageing and getting close to the end of its useful life (Too, et al., 2006)
- Current planning and construction processes do not provide a long-term focus on the asset (Too, 2011)
- The need to please the multiple stakeholders involved.

These challenges are just a few which have been creating a massive issue within performance, Too (2011) has reported on how the construction of infrastructure ends up at a reported high cost due to delays in the project, and sectors such as railways often fail to earn the revenue which ends up being a loss in profit.

The UK government has stressed the critical importance of efficient construction in the UK since 2011, one of the main changes was to introduce the use of BIM (Building Information Model) and enabling technologies throughout the building industry to promote working in a fully collaborative environment. Focusing on the Building Information Model, the use of BIM would be a minimum requirement by 2016 (HM government, 2013). The government construction strategy authorised Level 2 BIM to be used (level 2 BIM is distinguished by collaborative working, i.e., everyone related to the project uses their own 3D CAD models, but not essentially working on one single, shared model) on all public projects by the year 2016. Level 2 BIM does not just produce a 3D model, but several domain-specific models held together in a precisely provided single environment to store shared data and information.
(Highways England, 2015). "The initially estimated savings to UK construction and its clients is £2bn pa4 through the widespread adoption of BIM and is, therefore, a significant tool for

Government to reach its target of 15-20% savings on the costs of capital projects by 2015." (HM Government, 2012) – (Page 6 of the report).

Performance issues are very common within the construction sector and are a common trend in Government reports, Latham 1994 (Latham, 1994) has undertaken a major report which has concluded that:

> *"Previous reports on the construction industry have either been implemented incompletely, or the problems have persisted".*

Other reports such as Plan Radar (PlanRadar, 2022) and the NBS National BIM report (NBS, 2020) have pointed out the slow progression. Egan (Egan, 1998) has pointed out that:

> *"Nonetheless, there is deep concern that the industry as a whole is under-achieving. It has low profitability and invests too little in capital, research and development, and training".*

These reports expand on the potential reasons behind the lack of growth in performance and across these reports, which include the UK Industry Performance Report, 2016 (The KPI Team, 2016), there are common themes that will be expanded on below. In addition to these issues identified, the reviews have highlighted one of the trending factors to be that the design and construction activities are separated regardless of their being dependent on each other, sub-contractors are also underutilised despite their knowledge and skills as companies want to save costs and carry out works themselves even if it is not their speciality.

This study considers the term "Infrastructure" as both the economic and social infrastructure of the UK, which includes physical assets construction such as road, rail, water, and buildings. The study analyses organisations in the UK that construct infrastructure which include road construction, rail construction, buildings construction, and water treatment. Hence for this study, Infrastructure can be defined as the physical assets of an economy allowing the necessary operations of a country to take place.

2.3.INDUSTRY 4.0 DEVELOPMENT

In 2013, a German memo was released which was the first mention of "Industry 4.0", this strategy was highly technological and aimed to almost digitalise the manufacturing industry fully with the result being minimal human involvement (Moore, 2020). The construction industry is constantly changing, and client requirements are also constantly changing, any new trend in the construction industry is usually adopted by the whole sector, especially with the mandate of the

Building Information Model in the UK, the construction industry is already on its way to the digitalisation of project information and many other aspects of an organisation. Industry 4.0 is based on the concept of integrating the business and its manufacturing processes in addition to integrating all sectors within the organisation from clients to sub-contractors (Rojko, 2017).

Over the past 5 years, there has been a lot of study and research published on Robotics, electronics, computer science, and production engineering which has raised a lot of awareness of Industry 4.0 and its relevant subjects with the inclusion of additive manufacturing and intelligent manufacturing((Shaheer, et al., 2023); (Furrer, et al., 2023); (Viale and Zouari, 2020); (Koh, et al., 2019)). The industrial revolutions that have arisen over the past two centuries have been promoted which introduces new production modes hence enabling the emerging technology at the time (Longo, et al., 2017). As previously briefly described in Chapter 1, the introduction to steam engines saw the *first industrial revolution*, *the second industrial revolution* saw the application of electricity being introduced and finally, before our current industrial revolution, *the third industrial revolution* was introduced when the widespread of information technology and electronics product support started to be introduced (Longo, et al., 2017). The phenomenon of enabling a higher level of connection between information and products with people is now considered the fourth industrial revolution (Industry 4.0) which involves a mass range of innovation with the use of varied technologies, advanced materials, innovative products, and new manufacturing processes (Lu, 2017).

The concept of Industry 4.0 derives from advanced technology throughout the industrial sectors worldwide. The methodology is defined as the application of emerging technologies to transform current production methods to more machine-dominant processes and digital manufacturing (Oztemel and Gursev, 2018). It has been argued that Industry 4.0 does not only take into regard the integration of technologies but also takes into consideration the storing, sharing, use, and organisation of data and resources to allow a faster, more cost-effective, and sustainable way of delivering product and services (Piccarozzi, et al., 2018). The interest in Industry 4.0 and research on its related technologies have been growing at a fast pace, however, these studies have not been entirely focused on just Industry 4.0 but more on creating a relationship between Industry 4.0 and more topics, for example, Muller et al (2018) explore the relationship between Industry 4.0 and sustainability development (Muller, et al., 2018).

Paradigms within Industry 4.0

Weyer et al (2015) have described Industry 4.0 as three subdivided paradigms which are as follows:

- ***The smart product:*** This refers to machinery and objects which have been fitted with sensors, and controlled software and are connected to the internet. These smart products can store data and make use of that data with machine-related manufacturing, for example, this data can enable the machine to understand when to produce, what the parameters are for the product, and where to produce all resulting in the machine adopting the whole manufacturing process of the product.

- ***The smart machine:*** The smart machine refers to having a device that is prepared with machine-to-machine technologies such as Artificial Intelligence. With the use of these technologies, machines can solve problems and make decisions that would replace traditional processes within production. This system is an innovative system that uses open networks and semantic descriptions to enable communication between the autonomic machinery while other devices communicate with the local control intelligence which allows flexibility and efficiency.
- ***The augmented operator:*** The third and final paradigm is the augmented operator. This is a concept that focuses on the technological support from staff within the production system to operate and address the knowledge within the automated system. Workers within this production are usually there to monitor and verify the strategy of the production. The workers with these tasks usually play a big part in making strategic decisions and introducing flexible problem-solving solutions (Weyer, et al., 2015).

Based on the paradigms mentioned above, it has been suggested by other researchers that six principles are to be considered before the implementation of Industry 4.0 strategies. These principles are as follows:

Interoperability

The first principle of Industry 4.0 is interoperability; this refers to the ability of two or more systems to work and communicate together and understand each other's functions. This allows the ability for data exchange and knowledge sharing between the different systems. Interoperability is known to be a key advantage of Industry 4.0 as the machines and humans can connect and communicate throughout the automated procedures. Lu (2017) has proposed a framework of levels of interoperability and introduced four levels to the framework.

- *Operational interoperability:* This suggests the concepts, standards, languages, and relationships that are within the systems in use.
- *Systematic Interoperability*: This describes the methodologies, standards, and models.

- *Technical Interoperability:* Technical Interoperability demonstrates the tools and platforms that can enable the technical developments for these platforms.
- *Schematic interoperability:* Finally, this framework ensures that the information and data exchanged are understood within the different groups (Lu, 2017).

Kamble et al (2018) have confirmed that interoperability provides an environment where systems can accurately share information without any loss of data which results in higher productivity within organisations and cost-saving production (Kamble, et al., 2018).

Virtualisation

Virtualisation is utilised for monitoring processes and communication between machines. This shows that the machines are capable of monitoring physical processes. Sensors are linked to the virtual plant models and the simulation models which allows the creation of virtual objects that represent the physical objects (Mrugalska and Wyrwicka, 2017). With the possession of a virtual model, different scenarios can be simulated with the use of the data collected through monitoring. This simulation can identify potential risks or failures within the virtual model and enables operators to act before creating the physical assets reducing errors during operations (Kamble, et al., 2018).

Decentralisation

This paradigm describes having cable and independent devices where the operational staff can depend on more than one source of decision-making. This can be achieved using embedded computers which allow the operational staff or devices to have control over the decision-making (Marques, et al., 2017). Control systems that have been embedded into these machines can enable each device to make its own independent decision allowing efficiency in the decision making leading to more flexibility (Kamble, et al., 2018)

Real-time capacity

Real-time capacity refers to the collection and analysis of data while it is being produced. For a smart factory, real-time data is required to detect errors as they happen promptly. Real-time data is dependent on big data technology which allows the collection of data regarding the machines, products, and equipment from different sources within an organisation (Kamble, et al., 2018). The collection and analysis of the real-time data allow decisions to be made to positively impact the profit of companies that have implemented Industry 4.0 strategies.

Service orientation

The service orientation paradigm requires that the devices being used have the capability of meeting the output need of the users with the use of internet services. Enabling the production systems to be interconnected allows the concept of product to evolve to product-service (Lasi, et al., 2014). This paradigm implies that the users' practical needs are to be considered by the product meaning that it should be user-friendly for the convenience of the users (Kamble, et al., 2018)

Modularity

The final paradigm is modularity which refers to the devices of its components producing standards. This allows the assembling, replacing, and expansion of these devices or components, if need be, within the modular production system (Qin', et al., 2016). Modularity can provide smart factories with the capability of adapting to the capacity while saving costs to manage the seasonal changes and the changes in production that arise (Mrugalska and Wyrwicka, 2017).

As briefly mentioned, there have been a variety of definitions of Industry 4.0, Lu (2017) has defined Industry 4.0 as *"industry 4.0 as an integrated, adapted, optimized, service-oriented and interoperable manufacturing process in which algorithms, big data, and high technologies are included"* (Lu, 2017) technologies are known as being the key part of Industry 4.0 as the connection of industry 4.0 is maintained by the adoption of a variety of software's sensors, processors and communication technologies (Bahrin, et al., 2016).

Industry 4.0 is still in its early stages when it comes to the construction infrastructure sector (Machado, et al., 2019), over the past twenty years, there have been numerous technologies such as the Building Information Model (BIM) which have been adopted by most construction companies in charge of public sector projects, BIM has given the different disciplines in organisations a different outlook on how to improve construction at all stages (Jallow, et al., 2020). Based on a survey in 2017, 67% of UK manufacturers are aware that Industry 4.0 can provide benefits and opportunities, however only 25% feel that they understand these opportunities (McKinsey Digital, 2017).

Industrial production is being transformed by technologies, and these digital technologies are being currently used in manufacturing, if fully adopted by the construction sector can lead to better efficiency and enhance relationships between all disciplines in an organisation (Alaloul, et al., 2020). Nine main technology trends are included in Industry 4.0 transforming our industrial production.

The nine main technologies include Big *Data Analysis* where data is a crucial aspect as when the project is completed, asset management goes on and the more data collected in the construction stage the more the asset can be maintained efficiently. With Industry 4.0, the technologies produced are equipped and with the use of a successful IoT (Internet of Things), data accumulation and analysis obtained from technologies can enhance cross-system interoperation (Ram, et al., 2019). The second technology is *Autonomous robots* which were introduced into the technologies and eventually, robots will start interacting with each other and collaborate safely with humans working alongside each other. Robots would cost less as labour costs will reduce and the robots would hold a greater range of skills and abilities (Vaidya, et al., 2018). *Simulations* are being used more in the construction infrastructure sector. Creating these simulations allows real-time data to mirror the virtual model created which can also include machinery and humans. With machine simulations, operatives can test products virtually before the machinery is physically changed enabling less machine set-up time and increasing quality (Vaidya, et al., 2018). Simulations in the form of 4D sequencing are also a useful tool as site teams can visualise the planners' programme and understand the scope of work. *Horizontal and vertical system integration* allows Data integration networks then can evolve, and value chains can become fully automated (Vaidya, et al., 2018). *Internet of Things (IoT) links to t*he concept of Industry 4.0 as it is based on more devices being enhanced, this will then allow field devices to link and interact with each other. This aspect will allow real-time responses and decisions to be made (Bai, et al., 2020). *Cybersecurity* is another main technology to consider as with the change to Industry 4.0, communications and sensitive information are to be stored in a database to increase connectivity. Due to all documents being in a database, the security of machines and software is critical (Erboz, 2017). Sharing data through means of emails, USB, etc can be a risky one as the information shared may not be up to date or information can be lost in transition which is why *The Cloud* is considered one of the main technologies. Industry 4.0 is to improve the performance of cloud technologies, data can be shared in milliseconds and with a cloud database, unlimited storage space for information can be possible (Bai, et al., 2020). *Additive manufacturing* such as 3D printing is only at its prime stages, companies mainly use these to create prototypes of works creating individual items. In the future, Industry 4.0 allows additive manufacturing to be implemented and used widely to manufacture construction products such as lightweight designs which are complex (Vaidya, et al., 2018). Finally *Augmented reality* which is an interactive experience where the real-life world is generated by a computer, currently, augmented reality has taken over the gaming industry, and within the construction industry, it is in its infancy however in the future wider use of augmented reality will provide the construction industry with real-time information and improve the decision making within planning periods (Maynard and Ross, 2021). This study considers six main industry 4.0 technologies namely Building Information Model, 3D Models, Big Data, Drones, Geographical Information Systems (GIS) and Point clouds and digital survey. These technologies are considered the main Industry 4.0 technologies within the UK infrastructure sector.

Industry 4.0 is known to provide a platform that allows interaction between the different parties, employees, and the resources available to complete the task on hand (Waschneck, et al., 2016) Industry 4.0 promises to utilise technical systems to assist in managing complex and vital designs within construction improving interaction and coordination, leading to problems solving initiatives and decision making (Waschneck, et al., 2016). Small and Medium-sized Enterprises (SMEs) have been having trouble in adopting technologies associated with Industry 4.0, despite the mas research on Industry 4.0 itself, there is minimal research reviewing studies on Industry 4.0 adoption within the Construction sector and how it affects the organisation, identification, storage and sharing key information in a business/organisation, which is known as Knowledge Management (KM) within an organisation. (Lu, 2017). This study presents the significance of the fourth Industrial Revolution in terms of KM within the UK construction Industry. It demonstrates how Industry 4.0 can be useful in overcoming Knowledge management challenges while improving a business within the construction sector. This study is mainly focused on the UK construction sector to gain higher productivity and performance from the industry, as shown in Figure 2.1 from the UK Industry Performance Report 2017 (CITB, 2017), the construction sectors' Profitability and productivity have both been at a decrease since 2009. Based on the 2017 survey, productivity fell by 2.1% due to rising costs within the industry.

Figure 0.1: UK Construction Sector Profitability and Productivity

Industry 4.0 provides a digital interconnection between the whole supply chain in real-time which leads to data exchange being easy to handle and allows the supply chain to gain various benefits. Processes within the supply chain can benefit by gaining increased resources and efficiency in terms of energy consumption, material usage, and waste processing which leads to a reduction of costs while increasing productivity (Saberi and Yusuff, 2010). In addition to these benefits, Industry 4.0 also leads the way in developing innovative products and services while managing the innovative process and data flows from the use of the product to the development of the product (Yoo, et al., 2012). Despite this, data exchange within the supply chains in the construction industry faces difficulty in terms of technical challenges which is why organisations are reluctant to adopt and implement Industry 4.0 technologies fully as there is a fear of data loss (KIEL, et al., 2017).

In addition to all these changes, industry 4.0 adoption leads to the different departments within an organisational structure evolving together virtually in terms of product development and so much more. This change, however, requires the organisational structure to be changed which changes the culture or the organisation leading to social challenges such as the competence of staff and job losses to accommodate for the changes (Weyer, et al., 2015).

2.4.REVIEW OF LITERATURE ON THE DRIVERS OF INDUSTRY 4.0 STRATEGIES IMPLEMENTATION

Multiple factors drive Industry 4.0 initiatives for organisations, these drivers push organisations to implement Industry 4.0 (Bienhaus and Haddud, 2018; Nedelko, 2021; Menon et al, 2020). Hopkins (2021) has highlighted that the key drivers for organisations implementing Industry 4.0 strategies need to be fully understood to gain a successful implementation. Furthermore, Silva et al (2020) assert that there is a lack of literature on digitalisation and Industry 4.0 within the construction industry which the infrastructure sector is a part of. This creates a barrier to the understanding of these drivers. A literature review was conducted from a theoretical background of the resource-advantage theory and institutional theory to gain a wider perspective of drivers that encourage organisations to implement industry 4.0 initiatives. Keywords that were used to conduct the literature review include industry 4.0 drivers, industry 4.0 development drivers, industry 4.0 external pressures, industry 4.0 internal pressures, normative pressure, coercive pressure, and mimetic pressure. The platforms used to search for the literature include Google, the University of Wolverhampton Library, and databases such as Directory of Open Access Journals, Scopus, ProQuest, SpringerLink, Elsevier and Scholar.

Table 2.2 and Table 2.3 present examples of the results gathered on internal and external drivers.

Table 0.2: Literature review samples concerning external drivers of Industry 4.0 initiatives.

	Source	**Description**	**Location**	**Methodology of research**
Coercive pressures	Chen, et al. (2018)	Government environmental laws green innovation within a variety of industries.	China	Case Observations
	Qiu and Yang (2018)	Pressures to improve quality by customers heavily impacts the development of innovation for legitimacy.	China	Case study/Literature Review
	Lui, et al. (2016)	Institutional pressures from	United States	Survey/Literature Review

		stakeholders within the organisation enforcing strategies making decision-makers to comply.		
	Jallow, et al. (2019)	Government laws pressure organisations to adopt a certain level of innovation on projects.	United Kingdom	Interviews
Normative pressures	Chen, et al. (2018)	Increase in customer and community awareness of environmental sustainability pressuring organisations to enhance those factors.	China	Case Observations
	Berrone, et al. (2012)	Complying with social factors from customers' requirements to avoid business risk in the reputation of the community.	United States	Literature Review/Case Study
	Liao (2017)	Environmentally friendly practices implemented to attract key customers and gain a competitive edge.	China	Case Study

	Song and Zhao, (2021)	Institutional pressures push organisations to implement innovation strategies.	China	Questionnaires/Survey
Mimetic pressures	Bag, et al. (2022)	Managers pushing eco-innovation to improve organisations performance.	South Africa	Survey
	Mehrabi, et al. (2021)	Senior management pressuring innovative practices at a strategic level to boost competitive advantage.	United States	Survey
	Kung, et al. (2015)	Practices demonstrating empirical evidence of a positive impact on performance force organisations to mirror other firms to gain the same performance benefits	Global	Survey
	Zhu and Geng (2013)	Green environmental protection was implemented due to pressures exerted by competitors. Organisation	China	Survey

		mirror innovation to gain legitimacy.		

The authors have explored external pressures through various industries which have pushed organisations to adopt and implement new practices. The main outcomes show that pressure from external parties from the organisations can have a major impact on new strategies being put in place. One of the external pressures is Government Laws which fall under coercive pressures, this external pressure can have a major impact as organisations can face consequences if not adopted and implemented hence government pressures can be seen as a major influencing pressure towards organisations.

Table 0.3: Literature review samples concerning internal drivers of Industry 4.0 initiatives.

	Source	**Description**	**Location**	**Methodology of research**
Increased finances and performance	ZANDER and KOGUT (1995)	Pressure for innovative strategies exerted by the organisations needs to increase profit and improve financial performance.	Sweden	Literature review
	Cruz-Cázares, et al. (2018)	Market opportunities pressure decision-makers to implement technological advances resulting in lower costs for production.	Spain and Netherlands	Survey
	Albort-Morant, et al. (2018)	In the interest of managers and decision-makers, management	Spain	Case Study

		strategies are implemented as drivers to boost business performance.		
Productivity Increase	Cruz-Cázares, et al. (2018)	Top management goals are to increase production and capacity while reducing production costs through efficient practices.	Spain and Netherlands	Survey
	Albort-Morant, et al. (2018)	Organisations' commitment to increasing production capacity is vital to drive them to implement strategies towards the fourth industrial revolution.	Spain	Case Study
	Cai and Zhou (2014)	Organisations aim for eco-innovation drives the implementation of industry 4.0 initiatives to reduce production costs.	China	Survey
Innovation	Ciabuschi, et al. (2011)	Decision makers within organisations involved in innovation drive innovative	Global	Case study

		practices to be incorporated in their strategies to gain competitive advantage.		
	Ciliberti, et al. (2016)	Drivers derived from knowledge coming from the outside of the organisation driving innovations and new technology solutions.	Italy	Survey
	Meng and Brown (2018)	Organisations recognise technological advances and are driven to implement industry 4.0 strategies to motivate innovation within construction.	United Kingdom	Literature Review / Interviews / Survey

Organisations throughout the industry also benefit from internal pressure. As there are many competing organisations within industries, pressures to be the best forces organisations to adopt new strategies. For instance, Meng and Brown (2018) explored construction organisations implementing industry 4.0 strategies due to the recognition of the technologies within the sector. As these technologies are being adopted by other organisations, the infrastructure sector being aware of their use encourages them to adopt industry 4.0 strategies to keep up with other industries and gain an advantage. Despite efforts, challenges are still present as the infrastructure sector is quite different to other sectors due to the manner of their assets being linear and organisations tend to contain a range of functions which can make it difficult to integrate these technologies throughout the organisation functions.

EXTERNAL DRIVERS

External drivers' studies tend to focus on the analysis of the interaction between the environment and organisations. There have been many studies that explore multiple theories and this interaction such as institutional theory, stakeholder theory, and legitimacy theory. This study adopts institutional theory to explore the external drivers.

Organisations' social performance is vital for the business and their financial performance and competitiveness. Hence, it is of major importance for an organisation to consider social aspects for their success (Gadekar, et al., 2022). Organisational competitiveness is the focus of the institutional theory as it explores how the organisation adjusts and manages new working environments and showcases its credibility. In this study, organisational competitiveness refers to the development of industry 4.0 strategies and practices in terms of external supply chain and stakeholders. The institutional theory refers to how stakeholders (clients, customers, government institutions etc.) adapt from instrumentality to being focused on social values and consideration of its members (Fuenfschilling and Truffer, 2014). The nature of the institutional theory focusing on factors such as environmental aspect allows research studies to study large organisations of high scale, however, researchers have highlighted that there is a lack of support from institutional pressures to benefit organisational competitiveness (Kauppi, 2013). Meyer and Hollerer (2014) argue that the institutional theory considers all organisations as equal, hence avoiding the unique aspects between the organisations which will not be similar (Meyer and Höllerer, 2014). Within the infrastructure sector organisation in the UK, organisations vary from tier 1 contractors who are well established down to small subcontractors who are at a lower level of establishment within the sector and will not have a high reputation as tier 1 contractors. In addition, their vision and goals differ as they have different scopes hence their competitiveness varies and would have different means of increasing that competitiveness.

For organisations, it is vital to adapt to their matched institutional environment to assess and adopt the right strategies, technologies, and processes tailored to their organisation. This can be beneficial as they can improve their status within the market and avoid losing work from customers and clients. The institutional theory has not been heavily researched in terms Industry 4.0 development, however, there has been some focus by some researchers on this agenda (Fogaça, et al., 2022). The theory can provide benefits as it allows an understanding of the changes in technology and processes to be easily understood by the decision-makers which can push them towards Industry 4.0 development. For instance, Fogaca et al (2022) used the institutional theory to explore the development of industry 4.0 within organisational fields and country levels tailored to each as an induvial as both organisations and countries will be at different levels and statuses within the fourth industrial revolution. The authors have concluded that there is a need for more exploration of the varying pressures internally and externally.

COERCIVE PRESSURE

Coercive pressures are one of the aspects of the institutional theory which is the pressure that is introduced from societies within the organisation that can directly impact what rules organisations need to follow (Hasle, et al., 2014). Additionally, these pressures can have consequences when they are not acted upon by as the organisation may not be compliant with requirements set by these societies. Societies within the organisation include government bodies and clients who specify their innovative requirements at the start of appointing the contract (Martínez-Ferrero and García-Sánchez, 2017). Furthermore, pressures from the government can make a massive impact and tend to be the fastest way of achieving organisations implementing new strategies that are currently in date (Cahaya, et al., 2015). The societies involved within the organisation can use their powers to add pressure on organisations that lie within the institutional environment to add specific activities and innovations within their practices which if not adhered to will introduce consequences. Piroozfar et al (2019) supported this as they describe that the government forces organisations to conform to certain industry 4.0 technologies pressures through their standards and guidance, hence increasing competitiveness and improving their reputation (Piroozfar, et al., 2019). Sari et al (2020) argue that the legitimacy of an organisation can lead to the organisation becoming more sustainable through coercive pressures as then there is a dependence on these societies and institutions like the government as they will become the owners. Additionally, the factors and requirements coming from institutions such as the government mean that standards and guidance are most likely to be provided for organisations to adopt these activities (Sari, et al., 2020). However, Hasle et al (2014) argue that despite the influent government institutions have on organisations, there are still factors that can create barriers to these pressures. For instance, organisations not government dependent will tend to comply with the pressures but not to their full extent as there will be extra factors for organisations to improve such as resources to comply with the pressures where small and medium-sized organisations may not be financially able to comply.

Fitra Roman et al (2015) stated that government pressure can kick-start further pressure from key stakeholders. With the additional pressures from other stakeholders, this can enforce the strict enforcement of these pressures thus, encouraging organisations to implement industry 4.0 management practices and allowing innovation to occur. Organisations heavily value coercive pressures as they can benefit the business, however, the strategies can tend to be costly as organisations may be required to adopt complex and evolving activities which require heavy investment. The extra costs and complex capabilities that are introduced with these strategies tend to discourage organisations from implementing them as they are not fully aware of the gains and advantages they can achieve.

Coercive pressure's impact on industry 4.0 strategies has not been widely explored in literature, however, with the Building Information Model mandate from the UK government, many authors have discussed the coercive pressures advantage it has introduced to organisations within the sector. Consequently, it is of great value for coercive forces as they can result in organisations creating industry 4.0 value while ensuring they gain benefits on social, economic, and environmental levels and improve their financial status.

NORMATIVE PRESSURE

Normative pressures are pressures that are introduced by external stakeholders and have an impact and influence on organisations, such as the supply chain, managers, and customers (Cahaya, et al., 2015). The differences between coercive pressures and normative pressure are that compared to coercive pressures, the normative forces do not have the same forces as they are not regulations that organisations are required to follow which have consequences. Normative forces are usually followed purely for the benefit of the organisation, an example of normative forces is moral compliance. There is no authority from moral compliance and no power of enforcing consequences to the organisation, however, organisations will follow moral compliance as it would benefit the organisations' reputation and benefit trust with their clients (Martínez-Ferrero and García-Sánchez, 2017). Martinez-Ferrero et and Garcia-Sanchez suggest that the development of Industry 4.0 within sectors in the manufacturing industry has encouraged organisations lacking to adopt these new strategies to survive within their industry. Rodolphe et al (2019) argue that organisations are forced by normative pressures as they are standards that are yet to be enforced, however, organisations would be pressured by these forces to gain acceptance within institutions and increase their competitive advantage (Durand, et al., 2019).

Normative forces are seen to be easier to make decision, Pinsker and Felden (2016) argue that with normative forces, there is fewer added pressures compared to coercive pressures as there is no fear of consequences. Additionally, normative pressures originate from certain stakeholders rather than involving multiple stakeholders as it will be inter-organisational which can introduce more complexities in adopting these strategies (Pinsker and Felden, 2016). Regarding industry 4.0 development, there are many normative pressures and institutions on organisations impacting their strategic plans. This includes digital managers within the organisations and the International

Standards Organisation (ISO), customers, and many more. For the infrastructure sector, customers are key stakeholders as the construction of infrastructure heavily impacts the community where noise and air pollution can happen, and the final asset will be used by these customers. Customers, in this case, who are the community are now more aware of the impacts organisations within the sector have such as environmental hence applying pressures to adopt environmentally friendly means within the construction stages.

Chen et al (2021) have found that customer requirements are one of the main normative forces that influence decision-makers within an organisation as customers can heavily impact social and environmental sustainability of organisations (Chen, et al., 2021). Sari et al (2020) argue that normative forces such as customer pressure can impact innovation within organisations. The authors suggest that the involvement of professional institutions and academic bodies can accelerate these strategies' interest within organisations by keeping students and businesses informed on these strategies creating a deeper understanding.

MIMETIC PRESSURE

Mimetic pressure gets introduced from the organisation's activities, challenges formed push organisations to adopt processes and strategies to overcome the challenges either for a specific task or goal and reduce uncertainty (Chen, et al., 2021). The nature of these uncertainties can tend to introduce risks for businesses and impact their competitiveness, organisations can tend to follow their competitors who may have already implemented strategies to eliminate these risks successfully to gain reputation points and stay on par with their competition. Sari et al (2020) argue that mimetic pressures push organisations to mirror other organisations within their industry as if they have the same resources, competitive pressures arise, specifically for the infrastructure sector, organisations compete to win work which can be heavily impacted by strategies that overcome uncertainties that organisations contain. Additionally, Martinez-Ferrero et al (2017) argue that mimetic forces improve organisations cultural strengths within their company, however, these forces are tailored to the type of industry as strategies adopted by varying industries may be hard to compete with if factors such as resources are not similar.

Mimetic pressures are difficult to measure, hence organisations find it challenging to anticipate the value it brings. However, Hasle et al (2014) suggest that mimetic pressures can tend to be more convincing for decision makers as if they originate from managers and employees within the organisation the strategies are more easily adopted as the new strategies can be enforced by the originators themselves. Consequently, mirroring competitors and strategies that have proved successful can eliminate the complexities introduced by bigger stakeholders and address uncertainties within organisations, hence improving Industry 4.0 development.

Table 0.4: Pressures that make up "The institutional theory".

	Coercive forces	Normative forces	Mimetic forces
Pressure source	**Formal and informal pressures:** The pressure exerted by different organisations or stakeholders.	**Professionalisation pressures:** Pressure is developed through standardisations from professional bodies.	**Pressures arising from uncertainty:** Pressure exists when organisations seek to mirror other organisations to gain legitimacy.
Actions taken	- Industry 4.0 regulations and consequences evaluation. - Assessment of the internal capabilities of the organisation relating to Industry 4.0 development. - Adjusting strategies within the organisation to be in line with regulations. - Commencement of integrating industry 4.0 strategies to become compliant.	- Assessment of the implications of complying with standardisations and professional bodies. - Review of competencies within the organisation that are related to Industry 4.0 development. - Improving organisations' internal strategies to integrate industry 4.0 development to adhere to standardisations. - Commencement of integrating industry 4.0 strategies to become compliant.	- Review and assessment of competing organisations' development and behaviour. - Assessment of success factors within organisations. - Mirroring behaviour suited to the organisation and their status.

Samples	Standards mandated by Government bodies.	Compliance with standardisations such as ISO	Organisations adopting industry 4.0 initiatives to match competitors for example leading in innovation.

INTERNAL DRIVERS

Drivers for industry 4.0 development have been researched, however, internal drivers as a more focussed topic on industry 4.0 development has not yet been explored. Habraken and Bondarouk (2020) determined that the current literature on drivers of industry 4.0 adoption does not present an exact representation of industry 4.0 adoption drivers (Habraken and Bondarouk, 2020). Two theories have dominated organisations' behaviour that have been going through the implementation of industry 4.0 strategies, these are the resource-advantage theory and agenda theory. In this study, resource-advantage theory was used.

Resource-advantage theory can be explained as strategies whereby the resources, competency, and capabilities are put in place for the organisations' benefit of increased productivity and economic growth (Hunt and Davis, 2012). Penrose (1959) introduced a determination of the relationship between organisations' resources and their competitive status as the usage of these resources can majorly impact the performance of the organisation hence increasing competitive advantage (Kor and Mahoney, 2003). This theory investigates the organisations' resources and capabilities to properly draw them in boosting their competitive advantage by implementing strategies, this is in line with Patel et al's (2019) claim that the resource-advantage theory looks at the internal situation of an organisation which can determine their successfulness or failure when taking up a new market (Patel, et al., 2019).

According to Hunt and Davis (2008), the resource-advantage theory combines the concepts of the heterogeneous demand theory and the resource-based view of the organisation (HUNT and DAVIS, 2008). Resource-advantage theory interlinks the demand and supply within an organisation where the resource is defined as "the tangible and intangible entities available to the organization that enable it to produce efficiently and/or effectively a market offering that has value for some market segment" (Hunt and Davis, 2012). Hence, entities owned by organisations are available resources that allow production efficiently and effectively to provide value to organisations. Organisations need resources to meet requirements that are within their scope, resource characteristics that is to be considered include: rare, valuable, inimitable, and non-substitutable, this is known as the VRIN framework, which was built on by Barney (1991) and the VIRO framework was introduced (valuable, rare, imperfectly imitable, and organisational support) which has proven successful at a decision-making level (Barney, 1991), these terms are explored below;

- **Valuable:** Organisations that contain valuable resources can effectively plan and implement new strategies which boost efficiency and effective production. Valuable resources create products and services that are valuable to the customers allowing organisations to respond to risks and threats to the business (Cardeal and Antonio, 2012).
- **Rare:** The rare resources are those that are organisation specific and are difficult to mirror by other organisations. This makes organisations that have these resources unique and contain a competitive advantage. These rare resources refer to when organisations create more economic value than normal organisations within their market and this value is hard to be duplicated within other organisations (Dionisio, 2021).
- **Imperfectly Imitable:** Resources that contain the ability for other organisations to imitate are known to not be feasible as they can produce complexities or barriers to gain them. Barney and Hesterly (2007) suggest that these resources provide a competitive advantage for organisation only in the case that other competitors do not contain the same available resources or could obtain them (Barney and Hesterly, 2007).
- **Organisational support:** The VRIN framework did not account for support from organisations through structure and systems. These resources complement the framework as they strengthen the other resources within the framework to produce a competitive advantage (Barney and Hesterly, 2007).

Bature et al (2022) argue that organisational resources and their capabilities are key to their survival and in increasing their competitive advantage. Resources can be defined as the assets of the organisation and the organisations' capabilities relate to how the organisations use these assets (Bature, et al., 2022). Furthermore, the authors suggest that a resource can be valuable, following the VRIO framework, if there is the ability to be exploited and enhance positive environmental opportunities for the organisation. Talaja (2012) argues that there is a lack of research tailored to resource characteristics as resources within the VIRN framework highlight the value and rarity based on the competitive advantage they introduce to organisations despite the lack of practical evidence of this (Talaja, 2012).

Bresser and Powalla (2012), Murcia et al (2022), Chatzoglou et al (2018), and Pearson et al (2015), among others, have recognised the relationship between the capabilities and resources of an organisation their competitive advantage. The authors have agreed that competencies and capabilities are vital in competitiveness advantages for the organisations that took part in their research. However, Pearson et al (2015) argue that new and small organisations have significant challenges in terms of wishing to compete with the resources and capabilities to boost their competitive advantage as they may not be able to compete with larger and more established firms (Pearson, et al., 2015), (Chatzoglou, et al., 2018), (Bresser and Powalla, 2012), (Murcia, et al., 2022).

Industry 4.0 development studies in literature have not been explored from the perspective of the resource-advantage theory a lot as there is a lack of literature on the relation between the two. However, due to the nature of Industry 4.0, it aims to boost economic, environmental, and social value which are values that are taken into consideration for the resource-advantage theory. Hence, the resource-advantage theory should consider environmental, social, and economic issues that organisations face, thus tackling these challenges.

2.5. EVALUATION OF THE RESOURCE-ADVANTAGE THEORY AND INSTITUTIONAL THEORY

Both resource-advantage theory and institutional theory have been amongst the engrained theories that have been adopted when studying drivers of change. These theories have differences in terms of the behaviour of an organisation towards their development as the institutional theory focuses on the motivators of the organisation to conform to new strategies from external pressures, and with the resource-advantage theory, the organisations' motivations are considered where their available capabilities and resources are used to enhance competitive advantage. Additionally, within the institutional theory, external pressures (coercive, normative, and mimetic) force organisations to adopt strategies and systems to mirror other organisations to gain the same efficiency and boost economic, social, and environmental value, whereas the resource-advantage theory suggests that the organisations' capabilities and resources increase organisations competitive advantages through unique resources that affect the organisations' systems and structures. Section 2.4 of this chapter explores the literature on the driving forces for the implementation of Industry 4.0 initiatives at an organisational level with the adoption of a multi-theory approach (Resource-Advantage Theory and Institutional Theory). Table 2.5 summarises the evaluation and comparison between the two theories.

Table 0.5: Evaluation of institutional theory and resource-advantage Theory

	Resource-Advantage Theory	**Institutional Theory**
Contention	The influence exerted by organisations' resources and available capabilities which enhances the organisations development and performance.	The need for advancing organisation growth and success through adopting strategies with pressures exerted from external stakeholders.
Hypothesis	Organisations are driven by their available resources and capabilities.	Organisations are pressured by external forces to adhere to standards and requirements.
Emphasis	Organisations identify, develop, and implement strategies based on their capabilities and resources.	Conformity to external pressures.
Analysis Unit	Meso-level and Micro-level	Macro-level
Objective	Organisations within the same industry contain varying resources and capabilities which dictates the level of implementation and which industry 4.0 initiatives they can implement that ensure success and competitive advantage.	Industry 4.0 strategies aid the organisation in improving productivity and performance through adhering to institutional and stakeholder pressures, thus increasing their legitimacy.

2.6.LITERATURE ON THE VALUE OF INDUSTRY 4.0 STRATEGIES IMPLEMENTATION

Industry 4.0 strategies have an impact on all three factors of the triple bottom line approach for an organisation. Jayashree et al (2021) suggest that industry 4.0 strategies create a direct impact on the organisation including the factors within the TBL approach which is why organisations need to implement these strategies. The author has highlighted examples where industry 4.0 strategies improve organisational sustainability (Jayashree, et al., 2021). Kiel et al (2017) have stated that from the triple bottom line factors, the economic value gained by organisations through the implementation of industry 4.0 strategies has had more research compared to the other two factors, social and environmental. The authors have stressed the importance of business models within organisations incorporating industry 4.0 strategies as this has had a minimal investigation, hence organisations do not fully understand the business model around innovation. Furthermore, the measure of the benefits gained from Industry 4.0 implementation has proven difficult for organisations to measure which creates a barrier for decision-makers as they do not understand or envision the potential benefits. For this section, a similar process was followed, and database platforms were used to search keywords which are as follows: Industry 4.0 benefits, industry 4.0 organisational values, industry 4.0 environmental benefits; industry 4.0 social benefits, and industry 4.0 economic benefits.

Table 2.6 presents a summary of the findings from the literature.

Table 0.6: Literature review samples concerning value gained from Industry 4.0 initiatives implementation.

Values	Source	Description	Location	Methodology of research
Cost savings	Machado, et al. (2019)	New processes will lead to resource efficiency which enables organisations to reduce costs.	Global	Systematic literature review
	Ancarani, et al. (2019)	Due to high-quality production, organisations note a reduction in costs due to avoiding non-conformances.	Europe	Literature review
	Fitzgerald, et al. (2013)	Organisations rely on labour, with the reduction of labour costs, cost savings are noted	Global	Surveys

		with a reduction in turnover time and improved productivity.		
Improved stakeholder relationships	Machado, et al. (2019)	The availability of people in a network of information systems makes stakeholders engaged with the organisations.	Global	Systematic literature review
	Brozzi, et al. (2020)	Industry 4.0 implementation enables organisations to lower natural stress on stakeholders as being on a network collaboration can improve, providing confidence to stakeholders	Italy	Survey
	Brozzi, et al. (2020)	Organisations can have more flexible work providing a better working environment for their employees through implementing industry 4.0 strategies	Italy	Survey
Emissions reduction	Birkel, et al. (2019)	Energy savings were noted through implementing industry 4.0	-	Literature reviews / interviews

		initiatives and implementing renewable energy.		
	Stock and Seliger (2016)	Smart factories can be used to monitor energy supply and feedback to organisations where decision-makers can assess the best way to reduce energy consumption	-	Literature review
	Machado, et al. (2019)	Renewable energy is shared with other plants leading to energy savings for organisations.	Global	Systematic literature review

2.7.TRIPLE BOTTOM LINE APPROACH

Organisations and researchers have highlighted the importance of Industry 4.0 over the past decade (Jakubczak, et al., 2021). The "infrastructure" is known as being an asset which is vital for certain aspects including social well-being, the state's economy, and environmental reality, as it can have major impacts in benefiting the community and stakeholders. Despite the clear vision and outcomes, industry 4.0 adaption has been difficult to achieve at an acceptable level. Many researchers have explored the concept of the triple bottom line approach which was developed by Elkington (1998) (Elkington, 1998), with industry 4.0 strategies which they have deemed a good fit for organisations looking to implement industry 4.0 initiatives. Birkel and Muller (2020) presented the triple bottom line approach in accordance with industry 4.0 strategies implementation which considers Social (safer working and reduced stress), economic (production monitoring and faster delivery), and environmental (reduction of waste and improved efficiency). The triple bottom line elements are linked to each other where each element supports the other, this is displayed in Figure 2.2. thus, organisations that are looking to implement industry 4.0 strategies need to integrate their performances with the elements of the triple bottom line approach (social, environmental, and economic (Birkel and M.Müller, 2021).

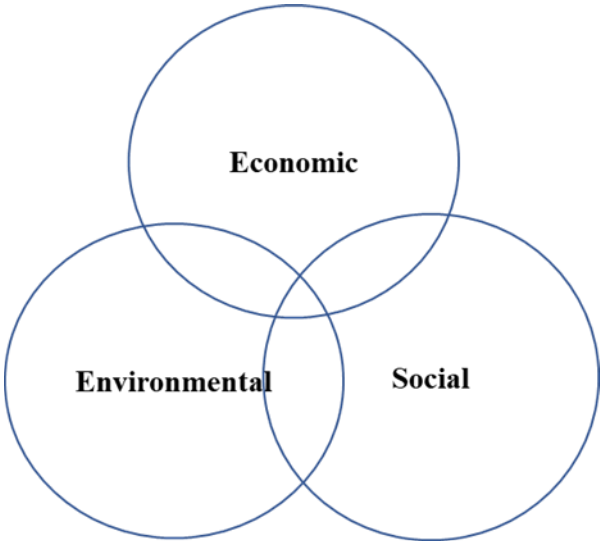


Figure 0.2: Triple Bottom Line Approach

It has been noted that the triple bottom line approach can benefit industry 4.0 supply chain management. However, Brikel and Muller (2021) highlight that there may be challenges in the interrelationship of the triple bottom line elements which may obstruct industry 4.0 implementation. Researchers have argued that there are blind spots where for instance, between the interaction of the social aspect of "reduced stress" and the economic aspect of "faster delivery", the reduction of stress for stakeholders and employees may be difficult to measure its impact during the interaction with faster delivery, the interrelationship between the elements of the triple bottom line approach demonstrate that for example, reduction of stress for employees can benefit the delivery time of the project. Despite this, the determination of measurement of this relationship and how they each impact each other is very difficult to conduct which has been highlighted by many researchers ((Khan, et al., 2021), (Braccini and Margherita, 2019), (Rahman, et al., 2020)). Researchers have suggested that calculating performance from the interactions between the three triple bottom line aspects can be extremely difficult. There still is no method available for conducting this measurement, hence it is recommended that the measure be conducted for the individual aspects within the triple bottom line, the measurement value outcome will be highly dependent on the capabilities, pressures from the external supply chain, and resources of the organisation (Khan, et al., 2021).

SOCIAL ASPECT

Social learning and sustainability for an organisation impact both internal and external communities according to Perry et al (2020). Social performance allows organisations to better the relationship between them and their stakeholders which improves their reputation within their sector. Additionally, stakeholders can gain confidence in the organisation through transparency which can enable them to add value towards the community (Khan, et al., 2021). Social performance for organisations is highly dependent on many factors such as government regulations, social pressure from customers and or external stakeholders, Kumar et al (2022) assert that unsustainable social practices should be eliminated which can be achieved by incorporating sustainable practices and solutions to their tasks and operations (Kumara, et al., 2022). Social performance is vital for organisations as it also impacts other aspects within the triple bottom line as social sustainability has a direct impact on environmental and economic sustainability, increasing social performance guarantees inclusion within the communities involved which improves governance. It should be observed that organisations should not just apply social sustainability that is requested by stakeholders or regulations by the government, for organisations to gain and improve social performance, it is recommended to go beyond the required social sustainability requirements.

ENVIRONMENTAL ASPECTS

Environmental performance can be described as the expenditure that can reproduce whether living or non-living (Khan, et al., 2021). Dzhengiz and Niesten (2020) note that environmental sustainability is key as organisations that utilise more resources if not environmentally sustainable can negatively impact environmental performance and raise footprints, while we currently are going through climate change (Dzhengiz and Niesten, 2020). This is the reason why Baz and Laguir (2017) have asserted that environmental issues need to be addressed by organisations which have been noted to still be emerging. Several researchers have stressed the factors that affect environmental sustainability for organisations which include stakeholders, customers, and business awareness of environmental sustainability ((Baz and Laguir, 2017), (Lieb and Lieb, 2010) (Usubiaga-Liaño and Ekins, 2021)).

Dangelico and Pujari (2010) have asserted that organisations need to reflect on three dimensions, namely, minimisation of energy, reduction of materials and the prevention of pollution which are to be incorporated within their activities hence directly impacting the organisations' performance (Dangelico and Pujari, 2010). These dimensions can be explored by implementing environmentally sustainable practices, Longoni and Cagliano (2015) have suggested that organisations should strategically configure their models with set environmental long-term and short-term goals in terms of environmental sustainability goals.

ECONOMICAL ASPECT

Organisations with good economic sustainability allow economic growth while considering environmental aspects and social aspects. Braccini and Magherita (2019) asserted that economic sustainability provides gains and profit for organisations, however, it also impacts environmental and social aspects where good economical practices positively impact an organisation's social and environmental sustainability. Researchers have stressed the importance of circular economy (CE) strategies to be adopted by organisations especially when implementing innovative processes, this allows the organisation or business to close the gap in resources as they become key drivers for the organisation improving their competitive advantage (Khan, et al., 2021).

Economic development is currently advancing which means that basic systems that are necessary for day-to-day life need to adapt to the changes. Organisations currently focus on improving their economic performance and lack focus on the social and environmental sustainability aspects which becomes a disadvantage as the three dimensions are linked and support each other in growth (Usubiaga-Liaño and Ekins, 2021). Economic performance differs from the other two aspects of the triple bottom line as it can easily be measured, the factors that are within economic performance include reduction of costs, resource cost reduction, increased productivity, and improved quality, among others which organisations can evaluate and measure performance (Löschel, et al., 2019).

The triple bottom line approach allows a systematic approach to dealing with environmental, economic, and social issues for organisations. The approach highlights the importance of each dimension as they are all interlinked and benefit from each other improving the organisations' long-term performance and sustainability goals. Thus, organisations need to consider all three dimensions to achieve improved performance. The triple bottom line approach was used in this study to understand the contributions that organisations in the UK infrastructure sector gain from Industry 4.0 strategies, this allows organisations to determine how they impact the various aspects of the world rather than focussing on aspects such as paper profit.

2.8. INDUSTRY 4.0 STRATEGIES CHALLENGES FACED WITHIN THE UK INFRASTRUCTURE SECTOR

Innovation within the infrastructure sector is a very common study within the industry especially in this age as we enter the industrial revolution of Industry 4.0. This research has been heavily built on previous research conducted based on the topic of study, it is highlighted that there are subsequent differences between the construction infrastructure sector when compared to the likes of the building, mechanical, and other manufacturing sectors in the construction industry within the UK. There has been a massive effort from the construction infrastructure sector to improve collaboration within their organisations' teams over the past years including the option of rethinking the procurement methods (Egan, 1998).

To add to previous research Markard (2010) also supports this theory that the infrastructure sector in the UK generally has different approaches in terms of innovation when compared to other sectors in the construction industry, this suggests that the division within the companies that make up the organisations affects adopting innovative technologies within the sector (Markard, 2010). The historic events within the sector are being carried on towards the future which must be changed for the infrastructure sector to grow and develop better practices.

The infrastructure sector undergoes vital changes at a time which provides issues for research on infrastructure topics, there are always befits and barriers within the transformation of the infrastructure sector which can affect different aspects such as financial aspects. The transformation of the infrastructure sector to this industrial revolution of digitalisation is heavily based on a multi-dimensional approach and according to Markard (2010)

> *"Takes into account the systemic interplay between technical, organisational, and institutional structures."* (Markard, 2010).

As briefly mentioned above, innovation within the infrastructure sector is at its peak with a lot of interest from researchers, organisations, and the UK Government. The Internet of Things (IoT) and Information Communication Technology (ICT) have recently been utilised more in the infrastructure.

The UK transport infrastructure sector is aware of technologies involved with the fourth industrial revolution, however, currently, the status of these technologies' adoption and implementation is far from where it could be within the sector. The ongoing projects within infrastructure in the UK are aiming to be smart infrastructure which would enable the UK to be advancing to the term known as "Smart Cities". This includes the use of technology within the infrastructure assets allowing the technology to be used within the operational phase of the asset, with the asset being smart, this will allow for better operation and maintenance of the asset.

Within the UK, the current state of transport infrastructure can be seen as upcoming and ongoing. Currently, motorways in the UK are being enhanced into Smart motorways, in addition, there are various projects throughout the different disciplines of infrastructure including rail with the High-Speed 2 rail construction which is aimed to be completed between 2029 to 2033.

The infrastructure sector commonly practices outdated ways of working occasionally. Despite there being solutions to improve current processes, the adoption and implementation of these processes are not in the position they are meant to be in comparison to other sectors within the manufacturing industry. There is a high lack of skillset within the sector in terms of new processes and ways of working specifically in technology, many employees within the sector have been in the industry for years and practice processes in a traditional manner as that is what the normal is considered for them.

OUTDATED PRACTICES IN THE INFRASTRUCTURE SECTOR

Industry 4.0 technologies are being introduced within the manufacturing industry, the technologies associated with the fourth industrial revolution and the goal of the industrial revolution are clear as described in Chapter 4, however, there are barriers to the adoption of Industry 4.0 strategies within the infrastructure sector in the UK, these current challenges will be discussed to understand their nature which will help in finding solutions to minimise these challenges with the use of a business model. This chapter is essential in providing a research rationale for Industry 4.0 Strategies within the infrastructure sector in the UK as it describes the current challenges within the transport infrastructure sector and why there is a need to adopt Industry 4.0 agenda within the sector.

POOR SKILLS

There is a massive skills shortage within the construction sector in the UK. With the new technological developments, teaching new skills to the younger generation is vital to obtain employable skilled people within the industry.

Within the infrastructure sector, the lack of skill has been blamed for decreased economic performance, British cities when compared to other Europe cities contain 11 out of 50 of the lowest skillsets in terms of education according to the Centre for Cities think-tank (Magrini, 2019). Based on a study undertaken in 2017, there were over four million low-skilled jobs worldwide and 56% of these low-skill jobs were in Britain (Magrini, 2019). Furthermore, the infrastructure sector contains a lot of under-skilled professionals when it comes to dated and advanced ways of working, namely technology based.

OUTSOURCED CONTRACTORS

Industries such as oil and gas sell parts of their business to make a profit from the rise in oil prices. Foreign students and staff are also relied on and with Brexit, international students are more likely to find it difficult due to the university budgets. Outsourced contractors are commonly used within the infrastructure sector to carry out work, this tends to lead to organisations outsourcing the work to not have these specific skill sets within their organisation as they are dependent on other contractors to carry out these works.

Delivery skills

It is no surprise that projects in the UK are not always delivered on time and budget, this is mainly due to the lack of knowledge being shared and the skill set to foresee the programme and analyse the projects' productivity. Due to this issue of unreliable delivery, the government's ***austerity programme*** will be put at risk. Issues that are a cause of this are:

- Organisations making firm commitments on costs and time scales for delivery.
- Wrong information on major projects that don't allow the proper measurement of performance.
- Major projects are not being prioritised (House of Commons Committee of Public Accounts, 2021).

UNCERTAINTIES IN CLIMATE CHANGE

With uncertainties when it comes to future climate change scenarios, the risk that comes with climate change is unknown currently and the industry must think of ways in which to anticipate the changes.

In the UK, there has been a drastic change in temperature as the average temperature has increased by between 0.8-1 degrees Celsius since 1980. The UK has witnessed its warmest twenty years on record between 1990 and 2020 which is also influencing sea levels which have risen by an average of between 1-2mm per year (MCCIP, 2020).

How would climate change potentially affect Infrastructure?

Climate change has been a major focus of research studies over the past years. Climate change proposes a big risk in terms of infrastructure globally. Infrastructure construction is dependent on factors such as the stability of slopes, vegetation, and the climate as these are all considered in infrastructure construction (Tang, et al., 2018). Climate change can introduce natural disasters which would heavily affect Infrastructure as the change in climate can result in landslides, floods, and more snow during winter periods which when melted can result in increasing peak flow

(Nissen and Ulbrich, 2017). The effects of climate change have been studied by Wu et al (2013) and the results of the study have shown that the risks involved with climate change to the global infrastructure due to sea, land, and overland surges potentially causing hurricanes which is why climate change should be taken into account when constructing infrastructure for future risk purposes (Wu, et al., 2013)

Infrastructure is generally affected by the change in the natural climate. Natural variability can introduce significant impacts on assets as weather events such as flooding can massively interrupt infrastructure as well as temperature rise which can affect the efficiency and capacity of some specific infrastructure assets (Dawson, 2015). The infrastructure sector has been implementing measures to respond to the climate changes we are facing however infrastructure projects take years to complete when the design, planning, and construction stages are considered, hence it is important to take into consideration the scale of changes in the future with the aim of future-proofing these assets for anticipated increased climate change. This can be potentially done by creating infrastructure solutions that consider a wide range of weather changes with the additional use of newly introduced technologies (Dawson, 2015).

Infrastructure organisations in the UK face many challenges when it comes to their processes. Communication being undertaken between the teams are different. With there being different common data environments, the different parties within organisations have different access to each CDE. This can cause loss of data through e-mails and can lead to the construction team and sub-contractors building to un-updated design drawings with the use of copies of the paper. Despite processes being put into place for organisations on how the sharing of information is to be conducted within the different parties of the organisation, information exchange and methods of communication are all over the place for most construction infrastructure organisations. There are strategies in place for most if not all organisations to improve processes within day-to-day practices, however the implementation and adoption of these strategies.

In about 1957, Dr Patrick J Hanratty, the creator of CAM (Computer Aided Manufacturing) took the chance to present the AEC (Architecture, Engineering, and Construction) with the Building Information Model and this was the first the model was heard of (Mandhar and Mandhar, 2013). BIM has become more popular over the past 10 years; this is mainly because it contains a lot of benefits compared to most other software. The biggest benefit of using the BIM if used from the start of the project is within the area of design development. With BIM being a 3D model, it is an ideal standard for examining the relations between several features of the project and evaluating their compatibility with the local topography. Transportation Infrastructure has a long lifespan and as mentioned before with BIM being helpful with maintenance aspects, it would be a suitable match to use it with the project. BIM does not only benefit the owners but also the contractors, architects, and everyone involved in the project at hand. For the contractors, it assists with communication by being visual. The tendering stage allows the contractor to give the client a display of how they would intend to go on with the project and how he has limited some of the construction to get the best quality as long as the best price (Smith, 2012). The software would not only benefit in the sense it could potentially win them the contract, but it also provides an opportunity to have an overview of the designer's detail and challenge it if a better outcome could be achieved.

Many benefits of BIM have been documented such as reduction in project costs, saving time, improving projects communication and collaboration, and project quality (Diaz, 2016). This Building Information Model also provides the means to increase design quality by detecting clashes between the different disciplines on the design before construction, BIM also improves the sharing of Information among the different stakeholders via a Common Data Environment (CDE), this allows the construction teams to always have access to up-to-date information for construction.

Silverio Rodriguez et al (2020) noted that many benefits have been recognised using BIM however there are also challenges faced when implementing and adopting BIM (Ana Karina Silverio Rodriguez, 2020). A summary of the key challenges is highlighted below:

• *More work at the start*

As BIM would require training for the prime contractors, designers, and so on, it requires a lot of effort at the beginning of the project. All these parties need a sit down to produce a collaborative model (Carlin, 2010).

• *Programmes' ability to work with other software*

With the programme's difficulty to work with other software, the company using BIM should consider how they are going to "consolidate, interpret and utilise the increasingly mountainous volumes of data" (Mason, 2014).

• *Stakeholder's software compatibility*

For the stakeholders to have compatibility, it is not necessary for them to be using the same software platform, however, it is necessary for the software being used by each stakeholder to be compatible as they would be able to exchange data and files. The issue that can arise from BIM is the incompatibility between software for these stakeholders. This however has a solution, as the IFC software programme enables compatibility between BIM and other software (Dowhower, 2010).

As noted above, the infrastructure sector has many challenges, these challenges were enhanced in March 2020 where the world faced COVID-19. COVID 19 added pressure on the above already existing challenges where the infrastructure sector as well as other sectors and businesses had to find ways of working while there was a global pandemic.

COVID-19 AND ITS IMPACT ON THE INFRASTRUCTURE SECTOR

The construction infrastructure sector is at a peak in terms of creating new infrastructure for the world. In the UK, the government set a goal back in 2010 with a national infrastructure plan to invest a massive amount of 600 billion pounds into infrastructure. The National Infrastructure Delivery Plan 2016 (HM Treasury and Cabinet Office, 2016) has stated the aims for the progress expected by the end of 2020 and early 2021 with the infrastructure building plan. Over 100 major road construction which includes the addition of over 1300 lane mileage is expected to be constructed and up and running by 2021 (HM Treasury and Cabinet Office, 2016). The rail sector is also being invested in with a major improvement in rail across the country, it is safe to say that the infrastructure sector has a lot of work over the next few years. In December 2019, reports of the first Covid-19 case were discovered (Reynolds and Weiss, 2020). The Covid-19 virus quickly took over Wuhan with the rise of pneumonia cases in the eastern part of China where the population was set at 11 million (Reynolds and Weiss, 2020).

Covid-19 quickly made its way to many different countries through the travelling population. The coronavirus was first seen in Wuhan China and was officially labelled as a pandemic by the World Health Organisation (WHO) on March 11, 2020 (Surg, 2020) at the time of writing, there have been reports of over 3 million cases worldwide, and just over 234,000 deaths which have been reported globally (Worldometer, 2020). The virus is an extremely uncertain virus that majorly affects people who are categorised as high risk with them having existing specific health conditions.

The uncertainties of Covid-19 are still ongoing with new variants being witnessed and the virus is very highly transmissible where health workers all over the world are being overwhelmed by the high demand for care (World Health Organisation, 2020). As briefly mentioned, there are at high risk, the WHO has identified that these are individuals with underlying health conditions such as diabetes, and cancer, in addition to individuals who are aged 60 years old and over (World Health Organisation, 2020).

The UK went into the first Lockdown on March 23rd, 2020, this was followed by the UK facing many more lockdowns between March 2020 and December 2021 to control the spread of Covid-19 with rules coming into place stating that everyone should remain at home and only travel to or from work (if you cannot work from home). These rules that have been put in place have majorly affected how all industries are conducting work currently. For infrastructure projects, the impact of lockdown may vary from country to country and project to project depending on the nature, size, and location. It also depends on the activities that need to be done on a project site. If the work could execute, then the health and safety risk assessments are to be done and the required personnel protective equipment needs to be provided by the organisations whilst following the working guidelines during Covid-19. Due to the current pandemic, there is a delay in work on most projects. This would have implications on the legal contractual obligations and have a negative impact on infrastructure business operations as most work tasks are conducted on-site and require people to be present. Long and short-term planning should be undertaken to prepare for a crisis if need be.

2.9. REVIEWED LITERATURE ON CHALLENGES AFFECTING THE IMPLEMENTATION OF INDUSTRY 4.0 STRATEGIES

The implementation of innovative technologies within the fourth industrial revolution is known to be difficult for organisations and their decision-makers (Aripin et al, 2019; Masood and Egger, 2019). Abdul-Hamid et al (2020) assert that industry 4.0 challenges are created due to its complexity as there are risks and reliability issues that create a challenge for organisations using existing traditional practices. The author has highlighted that these challenges can either originate at a dynamic level (lack of understanding, lack of integration of technological infrastructure or lack of skills and qualifications) or the challenges can originate at an organisation management level (organisations culture, lack of internet-focused networks within organisation. A systematic review of the literature was conducted to understand the challenges that prove to be a barrier to Industry 4.0 strategies. The systematic literature review process is explained in more detail in Chapter 4. The keywords that were used during the review were based on industry 4.0 challenges/barriers. The platforms used to search for the literature include Google, the University of Wolverhampton Library, and databases such as Directory of Open Access Journals, Scopus, ProQuest, SpringerLink, Elsevier and Scholar. Table 2.7 demonstrates a sample of the literature concerning challenges creating a barrier to the implementation of Industry 4.0 initiatives.

Table 0.7: Literature review samples concerning challenges blocking Industry 4.0 initiatives implementation.

Challenges	**Source**	**Description**	**Location**	**Methodology of research**
Lack of knowledge and awareness	Hovarth and Szabo (2019)	The lack of awareness as organisations are failing at increasing awareness of industry 4.0 strategies within and throughout their organisations.	Europe	Interviews
	Tortorella, et al. (2020)	Organisation learning to increase awareness and knowledge of industry 4.0 strategies are not being conducted efficiently.	Brazil	Survey
	Luthra and Mangla (2018)	Industry 4.0 is still emerging; hence organisations still lack knowledge of the right tools and processes to employ requiring deeper understanding.	India	Systematic literature review/Questionnaires
Lack of capabilities and competencies	Adolph, et al. (2014)	The key to determining the successful implementation of industry 4.0 initiatives is the development of competent staff within the organisation	Germany	Literature review

	MÜLLER and VOIGT (2017)	Organisations face major barriers in achieving general capabilities within their firms to accommodate the transition of a digital business.	Germany	Case Study / Interviews
	Shamim, et al. (2016)	Innovation capabilities are a key success factor for organisations implementing industry 4.0 initiatives as employees play a key role in contributing to organisational learning.	Global	Literature reviews
Financial resources	Erol, et al. (2016)	Financial investments are vital for Industry 4.0 implementation as new technologies would need investment, capabilities arising from these new technologies would require qualified staff and training.	Global	Literature review
	KIEL, et al. (2017)	The lack of funding for industry 4.0 systems and technologies is due to organisations focussing on profits rather than investment with those profits.	German	Case study / semi-structures interviews

	Mcmahon (2001)	Financial resources are a significant barrier to developing projects and small to medium businesses	-	Literature review
Organisations resistance	Hovarth and Szabo (2019)	Organisations face resistance from employees which is creating barriers in the implementation of industry 4.0 technologies.	Europe	Interviews
	Abdul-Hamid, et al. (2020)	Industry 4.0 initiative introduces process changes in which employees without the skill or not willing to learn to resist these changes.	Malaysia	Survey
	Saraji, et al. (2021)	Resistance to change by employees has been found as a challenge, however, human resources is a more essential barrier to Industry 4.0 initiatives implementation.	-	Literature review

Authors have noted multiple challenges found by organisations trying to adopt and implement industry 4.0 strategies. Some of the challenges noted are lack of capabilities and competencies, financial resources, and organisations resistance just to name a few. For instance, Shamin et al (2016) state that for innovation to be successful within an organisation, there must be competencies and capabilities that are within the organisation to allow these strategies to be successful as employees are key in the contribution of organisations knowledge-gaining. Through overcoming these challenges, organisations can then experience value gained through the implementation of industry 4.0 strategies.

The challenges that occur during the implementation and adoption of Industry 4.0 strategies have been noted in literature as shown above, however the analysis of these challenges and identifying their likelihood have not been conducted. This study aims to analyse the challenges found within the UK infrastructure sector when implementing and adopting Industry 4.0 strategies. To achieve this, the Graph Theory Matrix Approach (GTMA) was adopted. There are many analysis techniques that can be used to analyse likelihood of variables such as Saaty and Vargas' analytic hierarchy process (AHP) and Analytic Network Process (ANP) however, the results of these techniques output complicated diagraphs and results that are difficult to understand and compute (See Chapter 3, Section 3.8.7 for more details)

2.10. CHANGE MANAGEMENT WITHIN ORGANISATIONS

Communication of changes is vital for a business, where when new processes and business operations are introduced, the management of the changes needs to be communicated throughout the organisation to enable understanding and avoid difficult implementation (Shulga, 2020). ASQ (2022) defines change management as *"the methods and manners in which a company describes and implements change within both its internal and external processes. This includes preparing and supporting employees, establishing the necessary steps for change, and monitoring pre- and post-change activities to ensure successful implementation."* (ASQ, 2022). In addition, Nickols (2010) defines change management as applying structured procedures and a number of tools to address changes in organisational processes, this includes noting best practices, systems, and control mechanisms (Nickols, 2016).

Various literature provides the definition of change management which all seem to align. However, despite the alignment of these definitions, the route of change management for organisations and businesses is not clearly defined, it has been noted that both internal and external pressures can be rough to change which initiates change management (Kotter (2012), Lewin (1936), Connelly (2020)). It is a consensus among the authors that understanding the route of the change is vital in implementing the changes, especially as the changes will affect many aspects of the organisation such as its strategy, structure, processes, and culture. Hence understanding the changes is a key step to be undertaken by a business looking to implement change (Levasseur, 2001).

Organisations especially within the infrastructure sector implement changes to provide value to their business where they can gain competitive advantage as both internal and external drivers may request or need these changes (Cone and Unni, 2020). Lewin's change model, Lewin (1936) highlights that to successfully implement change, organisations must manage internal change processes. Organisations tend to fail within the adaption of internal and external change in processes which leads to a successful implementation of the changes in question. Brown and Weber (2012) asserted that change within organisations must be measured to understand the values and benefits, however, the measurement of change has always been difficult for organisations to quantify (Brown and Weber, 2012).

Lewin's three-step model has been one of the first change management models produced, where it focuses on the organisation making changes through mini steps internally. The steps include destabilising the outdated, migrating to the new, and restabilising the new, these steps have been built on by various authors to improve the model. Cone and Unni (2020) attempted to transform the model by using the modified Delphi technique. The Delphi technique includes questions to be presented to professionals and utilising the feedback to address change management using Lewin's model. The authors have argued that using the Delphi technique improved Lewin's model through the availability of expert opinions where they are engaged within the conclusion and consensus. Despite attempts at improving Lewin's model, it is inefficient for organisations as it takes time to adopt and complete when organisations look to a fast-paced change. Kotter's (1996) change model has also been explored, this model consists of eight steps and has been extensively used for change management within organisations (Kotter and Cohen., 2002). Kotter's eight-step change model unlike Lewin's is straightforward and easy to implement as found by many authors ((Wentworth, et al., 2018), (Pollack and Pollack., 2015), (Borrego and Henderson, 2014)). Behson and Kelley (2018) have reported the success of implementing Kotter's change model to manage change within the teaching evaluation system. They explained that the success of the change management model implementation is due to the educational context in the model fits. The authors further noted that the inclusion of members of higher education assisted in the success as there was guidance from professionals within the field where the vision of change was communicated which guided the team. Therefore, the inclusion of higher management and decision-makers is key for a successful change management strategy and can encourage change to move in the right direction at a desirable pace.

ORGANISATIONAL CHANGE FOR INDUSTRY 4.0

Organisations are noticing the need for Industry 4.0 strategies as we are now in the fourth industrial revolution, however, with the complexity of the changes introduced by Industry 4.0 strategies, organisations face major challenges when deciding to integrate these strategies within their business (Masood and Egger, 2019). Therefore, it is vital to address the change management for these strategies which have been explored by many researchers (Wolf, et al., 2018), (Reyes-Veras, et al., 2021), (Fareri, et al., 2020). Technological change is a difficult aspect to measure, additionally, change is currently growing globally raising competition between sectors and organisations. In addition to technological change, Fareri et al (2020) argue that the business environment is also subject to change as working conditions will be affected by new processes as well as newly introduced competencies and capabilities of individuals. Despite the clear need for change within organisational processes and operations, researchers have noted the difficulty of adapting to change. It has been noted that there are many factors which can affect the changes which stem from the start of the strategy where organisations need to have a clear vision which can enable leaders to lead this change while considering employees' resistance to change, communication of the change and development of the employees to adopt the change. There are four main change models within the research which include the Reference Architecture Model for Industry 4.0 (RAMI model) and the Minimum Viable Model (MVO model).

The RAMI model is based on the International Electronic Commission (IEC) which focuses on standardising technologies being adopted and implemented within architecture. Within the RAMI model structure, Yli-Ojanpera et al (2019) explain that the corporate strategy is reviewed and key elements and activities that are introduced by Industry 4.0 are incorporated at a strategic level (Yli-Ojanperä, et al., 2019). The MVO model differs from the RAMI model as according to Borili (2017), the MVO model focuses on lean production within the organisation through organisational change which highlights the gap between industry 4.0 and industries (Borioli, 2017). In addition to these two main models for industry 4.0 change management, Lozano's model also reflects change management in terms of sustainability which relates to industry 4.0 practices. Finally, Mckinsey's 7-S model portrays the different aspect within an organisation to change to adopt new processes and list out 7 key factors relevant for change (Kaplan, 2005). Table 2.8 explores the difference between the four models.

All four models present similar aspects while differing based on focus. The main similar aspect noted is the communication of change throughout the organisation, which is vital for any changes being implemented in an organisation. This implies that communication aligns the entire organisation with the vision and goals for the changes introduced. The second change that the models have in common is the training and upskilling of employees, this is another key aspect for change especially if organisations want a successful implementation as industry 4.0, staff and employees will need upskilling to gain capabilities and competencies that align with industry 4.0

processes. Management style has also been identified by authors as a key aspect as employees can benefit from having managers as role models to the new changes, additionally, management style can reflect on an efficient implementation of industry 4.0 initiatives. McKinsey mentions Shared values which is one of the changes which can determine successful implementation as with employees within the organisation having the same goal, new processes can become more easily accepted as they will be willing to learn and adapt to the new procedures.

Table 0.8: Summary of the four identified key change management industry 4.0 models

Reference Architecture Model for Industry 4.0	**McKinsey 7-S model**	**Minimum Viable Model (MVO model)**	**Lazano's Model**
- Strategic level organisational change.	- Change in strategy	- Bridging the gap between technology.	- Employee upskilling.
- Management systems review and definition. - Integration within the entire organisation. - Collaboration and communication of changes throughout the organisation. - Upskilling of employees.	- Change in organisational Structure. - Change in systems within the organisation. - Staff changes. - Skills updating - Change in Style/Culture. - Shared Values	- Building individual capabilities. - Creating and communicating of the new policies. - Creation of procedures in line with Industry 4.0	- Continuous training and learning. - Communication of practices and increasing awareness and knowledge in the organisation. - Incorporation of management and all business practices within new processes.

This study used McKinsey’s 7-S change model which has been identified as the most suitable for implementing industry 4.0 strategies as part of the UK infrastructure sector organisations. there were multiple reasons why McKinsey’s 7-S model was chosen. Firstly, it considers shared value which is critical for organisations for industry 4.0 strategies as industry 4.0 processes affect each level within the organisations and if all parties have the same shared value, then resistance to change can be minimised. Secondly, changes in organisational structure are a key part as new roles and responsibilities with additional competencies and capabilities will be introduced. Finally, systems are also an integral part of industry 4.0 processes as technologies and automation is involved within most, if not all, industry 4.0 strategies which can accelerate and lead to a successful implementation within organisations.

2.11. BUSINESS MODELS

Innovation can be said to be disruptive as adopting new practices tend to be challenging with changes in processes, business model creations can assist in the understanding of these new processes for organisations looking to adopt new practices and processes (Jallow, et al., 2022). Osterwalder and Pigneur's (2010) business model canvas has been used more frequently over the past few years and has become one of the major tools being used by entrepreneurs (Benjaminsson, et al., 2019). The business model canvas is a tool used to describe, analyse, and design business models. Organisations from different sets of skills have tested the business model with an immense success rate in describing their organisations’ current business model allowing the manipulation of their strategic approach to new and better alternatives (Slávik and Bednár, 2014), in addition to this, the model displays the elements that make up the business model. The canvas itself is made up of nine elements which contain consider four main areas within a business which are customers, offers, infrastructure, and financial viability.

The business model canvas was designed to assist entrepreneurs in analysing their business model to help generate profit within their business, moreover, it has been used for much more than just this purpose, for example, the well-known business model you (Umar, et al., 2018). Besides the business model canvas, the VTFD business model usually referred to as the tech business model is quite popular within tech businesses. Despite the popularity of the VTFD model within tech, Osterwalder’s business model canvas has been the most popular framework which allows the understanding of the creativity required for new processes while considering sustainability, innovation, and competitiveness (Vlachopoulou, et al., 2021), the business model canvas considers nine factors which are as follows:

- **Customer Segments:** This segment defines the customers that are the target for the company to present value.
- **Value Proposition:** The Value proposition cell provides an insight into the organisation's products and available services where the value may be both qualitative (e.g., client satisfaction) or quantified (e.g., budget, time). Furthermore, factors within innovation should be recognised such as performance measurements and reduction of risks.
- **Channels**: The Channels cell defines the communications routes for the parties involved within the organisation.
- **Customer Relationships**: This cell highlights an explanation of how the relationship between customers and clients is affected.
- **Revenue Streams**: This cell explains the flow of revenue within the organisation.
- **Key Resources**: This outlines the assets that are required to enable the model to be successful.
- **Key Activities**: This cell highlights the key actions to be taken by organisations to allow the model to function successfully.
- **Key Partnerships:** This cell within the canvas describes the network of partners that are required to enhance the business model where the required resources are obtained.
- **Cost Structure:** This cell defines the cost acquired to allow the business model to be in operation.

For this research thesis, Osterwalder's Business model canvas has been selected to assist the implementation of industry 4.0 initiatives within the UK infrastructure sector. Osterwalder's canvas considers innovation and sustainability, hence well suited for this research study. The adoption of this business model canvas can enable organisations to have a clear vision of what is required for each block within the canvas allowing the understanding of how to successfully implement industry 4.0 initiatives.

2.12. SUMMARY

There are a lot of sectors within the construction industry itself and in addition, the infrastructure sector involves many different types of construction varying from Roads, Rail, and Schools, just to name a few, which can be split further into Social and Economic infrastructure. There are a variety of parties involved within an organisation constructing any infrastructure asset, there have been an increasing number of Joint Ventures in the UK involving different organisations working together to complete the asset construction process.

The UK government has visualised the need for more infrastructure to be constructed due to the increase in population rate. There is a need for more infrastructure and/or improving the current infrastructure to increase capacity using current assets already constructed.

The UK government has planned a National Infrastructure Plan which is a plan on improving infrastructure over a 10-year. This plan involves the introduction of an innovation strategy for road construction and in addition to this, the Building Information Model was mandated back in 2016 for public sector projects which is a push for all projects being conducted in the UK to become digital. The UK government aims to increase capacity to accommodate population growth and improve the economy.

In the UK, the infrastructure sector is currently being enhanced as per the UK Government strategy introduced to improve infrastructure in the UK and boost the UK's economy. There are various projects ongoing that are government funded, in addition to this the government has put in place various digital strategies including a mandate of the Building Information Model to enable their projects to become more efficient and productive.

The infrastructure sector construction practices also involve a lot of outsourced staff. Due to this, the outsourced contractors may not have the technical skills required for Industry 4.0 agenda, in addition to this training may not be available for outsourced contractors which can affect the adoption and implementation of Industry 4.0 agenda on projects due to not every member of staff on a project do not have the required skill set for these new processes. Climate change is also a massive factor in the infrastructure sector, climate change can affect existing infrastructure massively and proposed infrastructure construction projects also need to consider future climate change implications on infrastructure such as landslides and flooding.

Despite there being technologies available to allow the fourth industrial revolution to boost, the infrastructure sector is behind in adopting Industry 4;0 agenda. However, the breakthrough of Covid-19 in December 2019 has encouraged the adoption of new technologies and digital processes to be adopted within the sector. This has allowed work to carry on during Covid-19 as lockdown rules and social distancing meant that staff members were and still are at the time of research bound to work from home. The availability of these technologies allowed work to carry on, especially the use of the Building Information Model and cloud storage.

This research benefits from providing insight into the infrastructure sector and Industry 4.0 strategies with the research questions and objectives developed. Within this study, research questions 5, 6, and 9 have been partially answered due to the scale limitation of the collected data. Five large organisations and 8 small to medium organisations took part which means that many other organisations may have a different level of implementation of industry 4.0 strategies and may also be gaining different benefits and value through the strategies, the remaining seven research questions have been fully answered. Research objective 8 has also been partially addressed as a sample of the Business Model framework for one of Industry 4.0's technologies, Artificial Intelligence, which was developed. Due to Industry 4.0 strategies containing multiple technologies, each technology, and digital advancement would require different criteria for mapping into a business model, hence a sample was chosen to be presented. The remaining research objectives have been fully addressed for this research.

CHAPTER 3: RESEARCH METHODOLOGY

3.1.INTRODUCTION

This chapter justifies and explains the methodologies which have been applied to this study. Before describing the data collection methods in detail. The ethical considerations are also discussed along with the justification of the reliability of this study.

In this chapter, a range of research methods are discussed, and the data collection method and technique implemented to collect the primary data will also be detailed as the achievement of providing answers to the research questions. In addition, this chapter provides the connection between the methods and the adopted paradigm.

3.2.RESEARCH PROCESS OVERVIEW

A research methodology discusses the procedures for the thought process that is applied to an investigation to find answers (Fellows and Liu, 2015), the research methodology supports the investigation being conducted by the researcher and this leads to the contribution of knowledge, with this being said, the research methodology can be considered as a strategy in which an investigation is used and consists of the research philosophy, approach and finally research technique (Fellows and Liu, 2015). The methodology chosen has been adopted to achieve the aim of this research. This research has been conducted in four phases:

- Phase 1: Conduct a systematic Literature review.
- Phase 2: Collection of Data
- Phase 3: Conduct Data analysis.
- Phase 4: Results distribution

The nature of this study is relatively new and has been based on the rational approach, the research begins with a systematic literature review conducted to understand the infrastructure sector and its position within the fourth industrial revolution, this enabled the understanding of the research initially and allowed the identification of the objectives of this research. A qualitative research approach was selected to investigate the research questions identified. Creswell et al (2007) describe a qualitative research study as a study that contains several strategies that may share some characteristics; however, each strategy contains a specific scope of procedures. Within the strategies qualitative research can use; action research, case study research approach, ethnography, grounded theory, and narrative research (Tashakkori and Creswell, 2007), these five approaches can also be used within a quantitative research approach. A systematic review of the literature was the first step before data collection, to gain knowledge from existing background knowledge based around the topic. Conducting a systematic literature review assisted in establishing the research questions which were answered either by the literature analysis, however, not all questions were answered through the review of the literature hence further research is to be conducted to gain answers. Producing a literature review utilises existing work which has been conducted by researchers or academics (Evans and Popova, 2016).

Analysts have pointed out that semi-structured interviews are the most used by qualitative researchers (Alshenqeeti, 2014). This type of interview also has set questions like the structured interviews which have been prepared by the researcher, however, when this interview is being conducted the structure of it is mainly dependent on the responses provided by the interviewee. The questions asked by the researcher are based on the topic at hand however the interviewee is free to explore beyond the research question allowing flexibility to gather more in-depth information for the researcher (Adhabi and Anozie, 2017). As the nature of this form of interview is flexible, they can be conducted either on a personal level or within a group, however, conducting this form of interview with individual interviewees will provide a more in-depth interview where the researcher can highlight personal opinions. Group semi-structured interviews are also beneficial to a researcher as having a group discussion on the topic will allow the researcher to gather more information and opinions as a collective, with this being said, it is acknowledged that semi-structured interviews are an ideal method of collecting data for qualitative research (DiCicco-Bloom and Crabtree, 2006). This study involves thirteen Organisations within the infrastructure sector, five of which are large organisations and eight small-medium sized organisations. Due to the saturation of infrastructure organisations in the UK, which is the area of focus of this study, the number of organisations is deemed as suitable. Hennink and Kaiser (2022) investigate the saturation required for qualitative research using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher, et al., 2009), and it was shown that the level of saturation for the number of interviews lies between 9-17 and the number of focus groups lie between 4-8. This falls in line with the sampling size for this research study (Hennink and Kaiser, 2022). Purposive Sampling was adopted for the sample selection of this research, this sort of sampling method is a type of non-probability sampling which can be known to be judgemental and selective. This type of sampling involves a group of non-probability sampling techniques being adopted where the sampling is dependent on the judgment of the persons conducting the research for selections such as the people, organisations and cases being used for the research (Emerson, 2015).

For this study, the interview questions were created to extracting what change management strategies for Industry 4.0 agenda and the adoption and implementation of these strategies in the UK infrastructure sector. Primarily the participants were asked questions designed to gain knowledge on what experts in the industry think about the infrastructure sector and its position in the fourth industrial revolution. The initial question asked was: What do you think is the status of the infrastructure sector concerning digitalisation? This question introduced was aimed to gather information on the current knowledge of the experts and understand digitisation and its status in the sector. Consequently, the interviewees were asked: Given your role in this organisation, please explain what does “industry 4.0” mean to you and your organisation? This question attempted to gain an understanding of the organisations that took part in the study perspectives of the fourth industrial revolution. The following questions were designed to gather an understanding of the organisation’s awareness and knowledge of the fourth industrial revolution and recognize where organisations lack understanding and knowledge of these new strategies and technologies.

The interviews were conducted from April 2021 to June 2021 and the duration of the interviews was between fifteen to thirty minutes. The interviews were conducted in the City of London in the United Kingdom, although the results gathered are from different parts of the UK and not limited to London, due to Covid-19 restrictions the interviews were held remotely as fact-to-face were not possible, hence all interviews were conducted while the researcher was in London virtually.

To dissect the data collected and gain a deeper understanding of the data, a thematic analysis was conducted. The initial step includes the transcription of the audio interviews, the data was then assigned codes which were developed with the use of the “open coding” mechanism which has been produced by DeCuir-Gundy (2012). The term open coding is a process which involves the labelling of the raw data collected in different categories and headings to aid the future analysis or organising and identifying relationships between the codes introduced by the researcher. The codes were then assessed with the use of content analysis and thematic analysis. Nvivo 12 software was used as the answers from the interviewees contained a mixed information nature where the responses contained more than one subject at the same time, following the thematic analysis, tools, and approaches such as Graph Theoretic and Matrix Approach (GTMA), Total Interpretive Structural Modelling (TISM) and Fuzzy MICMAC were used to further analyse the responses. These are presented in Chapters five to nine exploring detailed explanations of the findings that have been collated through this research. Business model frameworks were then developed from the findings of the results.

3.3.RESEARCH DESIGN

The research topic is quite diverse as in its nature, the term industry 4.0 is quite a varying topic. During the research, the strengths and weaknesses of the research design should also be considered (Creswell, 2007) where the best-suited research design is to be selected to allow the research responses to be suited to the research questions demonstrated in Chapter 1. The research design enables the researcher to gain clarity of the research path and defines aspects such as the research philosophy and strategy, this is presented in Figure 3.1 which demonstrated the latest version of Saunders's "research onion".

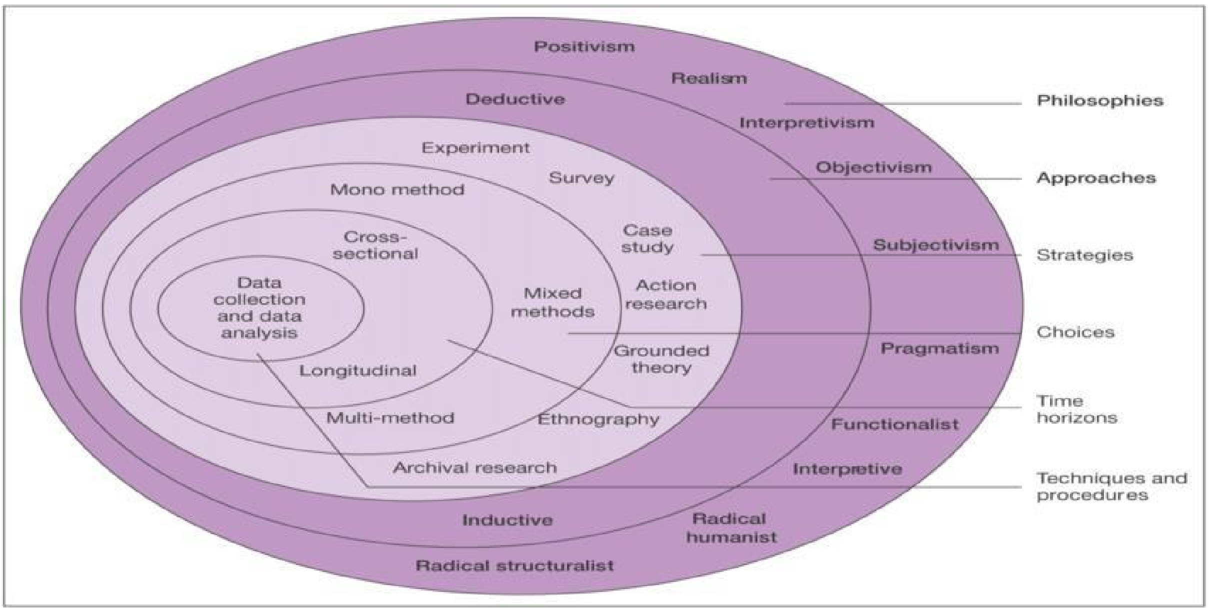


Figure 0.1: Saunders Research Onion

(Saunders, 2009)

3.4.RESEARCH CLASSIFICATION

Research philosophy

At the start of research, a perspective should be adopted and implemented by the researcher, this perspective is referred to as the research "philosophical paradigm" (Saunders, 2009). Saunders et al (2009) have reported that the research philosophy explains how the researcher visualises the world where the researcher's assumptions are highlighted supporting the research strategy selected to achieve the objectives. Research philosophy is split into three main categories, which are the epistemology, ontology, and axiology (method) (Saunders, 2009). De Langhe and

Schliesser (2017) have argued that research philosophies are dependent on the researchers' views which are derived from the ontological, epistemological, and axiological assumptions (Langhe and Schliesser, 2017). Figure 3.2 illustrates the dimensions or research philosophy described by Saunders.

Epistemology

Stanford (2020) describes epistemology as knowledge, this term is derived from the Greek word episteme (Stanford, 2020) which means knowledge. In simple terms, epistemology describes how knowing something is the truth or reality. This focuses on the base of human knowledge in the world. Schwandt (2000) expresses it as the justification and nature of knowledge. Considering epistemology in this research, a few questions were raised; is the knowledge for this research something that can be acquired or is it based on personal experience? Where is the knowledge coming from? What is the relationship between the source and the knowledge gained? (Schwandt, 2000), these questions take a major part of any research as they would allow the researcher to discover new horizons instead of only what is known and would also allow the understanding of the research paradigm.

Ontology

The ontology of research is the assumptions that we make to convince ourselves that something is real or makes sense (Scotland, 2012). Reality is mediated by our senses hence it is dependent on the person; ontology is the theoretical study of the nature of existence or reality. which ontology helps the researcher in conceptualising the nature of reality and what is believed to be known as reality by the researcher, this allows assumptions of the nature of the nature of reality which is crucial in determining the meaning of the data collected.

Axiology

The axiology of research can be defined as the part of the philosophical approach that focuses on the study of the value provided by the study (Saunders, 2009). Humans are wired to produce actions that provide value (Heron and Reason, 1997). Heron and Reason have argued that the researcher illustrates their axiology thought by showcasing their original judgements regarding the research being conducted and what approach they have selected to undertake the research. It is argued by Mingers, that a research study is more of a process rather than a discrete process which usually involves many different phases and tasks to achieve the result which is obtaining valuable data with the use of different arguments to justify the outcome (Mingers, 2001).

Method

Methodology is a term that can be used to refer to a variety of things. A methodology includes a research design, methods, approaches, and procedures utilised while undertaking an investigation that has been planned out to find out something (Keeves, 1997). The methodology of research is generally also including the data gathering information, the participants involved, how this data was collected, the data analysis etc. to summarise this, the research methodology articulates the process of research to expand on the research problem, and this also includes any limitations and assumptions made during the research.
The methodology allows the researcher to answer the question "How can I obtain the relevant data, knowledge and understanding required to answer the research questions and make a contribution to knowledge?" (Loomis and Pepinsky, 1948).

The terms ontology, epistemology and research method approach provide the opportunity for the researcher to explore different method approaches and go through critical reflective thinking throughout the research enabling the researcher to fill in the missing gaps between the research approach, research findings, the contribution provided to knowledge and finally how the research then provides information to the professional practices (Cole and Chase, 2011).

As described in the aims and objectives, this study aims to identify and understand the potential that Industry 4.0 strategies can bring to the infrastructure sector, furthermore, other technologies which are associated with Industry 4.0 that's just heard of and not practised within the infrastructure sector. When it comes to the ontological philosophy, this involves the position in which the infrastructure sector in the UK views the Industry 4.0 strategies within the industry and which experience they have had with these approaches determining their views on Industry 4.0. Regarding the epistemological philosophical position, this research adopts the interpretivism approach as the researcher tries to gain an understanding of the view from the infrastructure sector employees and staff mainly to try and understand how Industry 4.0 strategies can affect the sector and to answer the question *"why the infrastructure sector should adopt Industry 4.0 strategies".* Furthermore, this research aims to analyse the current use of Industry 4.0 strategies and technologies within the infrastructure sector in the UK to create a competitive advantage for the UK, the state of these strategies is analysed, and adoption challenges and benefits are described highlighting best practices with the use of the Business Model Canvas.

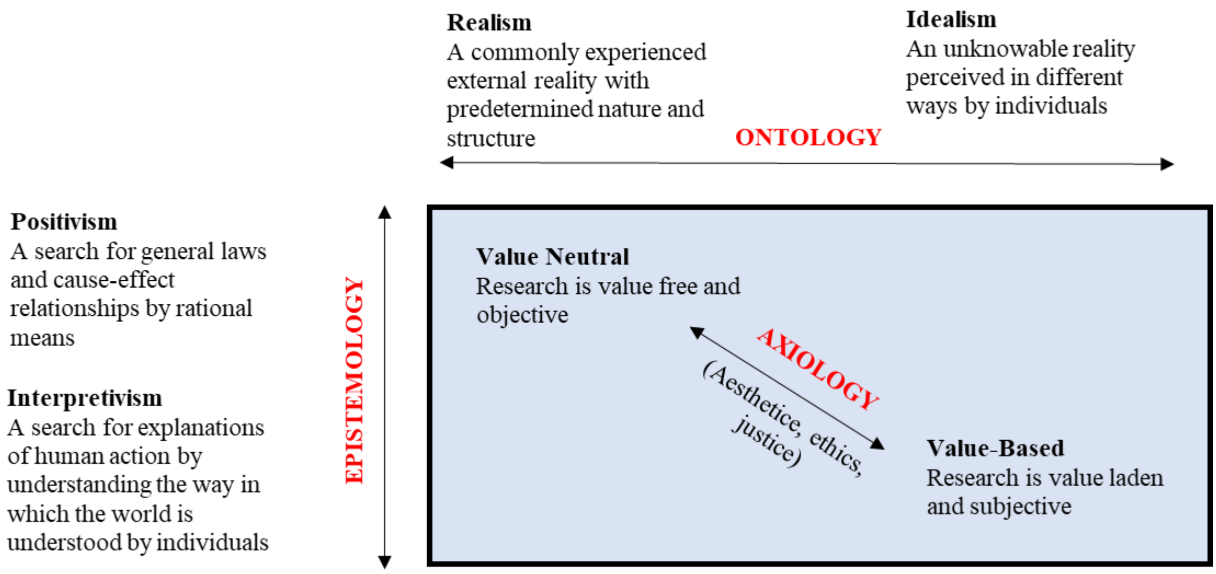


Figure 0.2: Dimensions or research philosophy described by Saunders.

(Dawood and Underwood, 2010)

3.5.RESEARCH APPROACH

A research approach can be described as how the theory of a topic has been recognised (Saunders, 2009), this establishment leads to the researcher categorising which approach is suitable, the three main categories for approaches are inductive, deductive, or abductive approaches. Each of these approaches will be discussed further below in subsections to fully explain their theories.

3.5.1. INDUCTIVE APPROACH

The inductive approach which can also be called inductive reasoning initiates with observations and theories being anticipated during the research process and especially when it is concluding (Thomas, 2006). An inductive approach is regularly adopted when subjective ontology is being used which can be referred to as a ***base-up*** approach as it goes from a specific to a general approach (Zalaghi and Khazaei, 2016). Liu (2016) has suggested that the main reasoning behind the inductive moving from specific to general observations is to broaden the theories that are being thought of, hence the research process initially starts by focusing on a particular observation allowing the researcher to pick up on patterns and formulate a hypothesis that can be discovered and finally achieving a general assumption on the theories (Liu, 2016) Figure 3.3 demonstrates the steps in which the inductive approach reasonings take place.

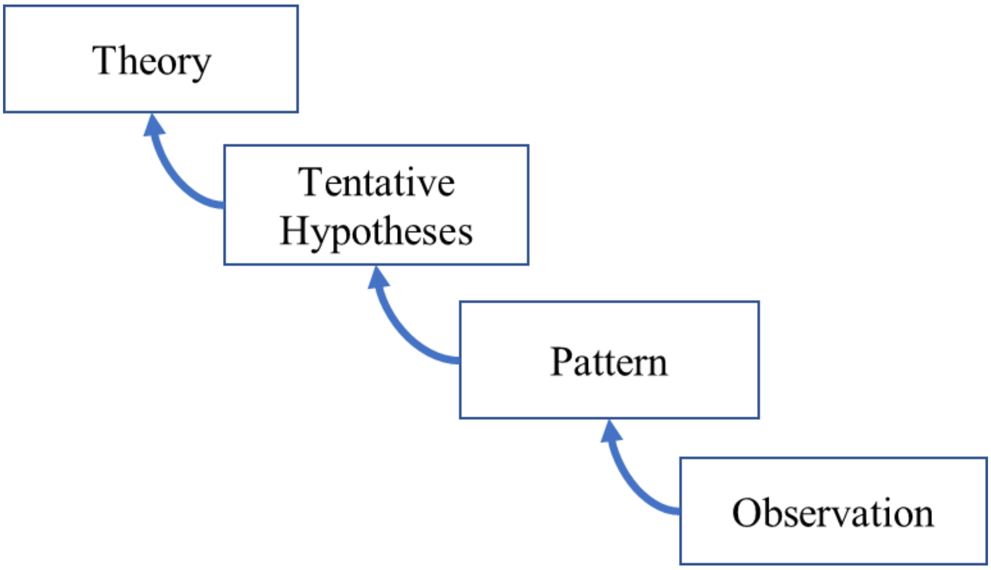


Figure 0.3: Inductive research approach

(Trochim, 2006)

3.5.2. DEDUCTIVE APPROACH

Within a deductive approach, sometimes informally called the ***Top-down*** approach, a theory goes through processes and is methodically trailed and tested (Trochim, 2006). This type of research approach relates to the objectivist ontology and is usually adopted while conducting scientific research where logical clarification is required to justify the research outcome (Zalaghi and Khazaei, 2016). Development of theory at its early stages usually leads to the growth of a hypothesis which is then tested which can assist in validating or regulating the initial theory through repetition of the testing process (Trochim and Donnelly, 2006). Trochim and Donnelly have described the deductive method as going from a broad theory, to filtering it down to a specific hypothesis through observations addressing the hypothesis. This then leads to the testing of this theory with specific data collected to either confirm that the original theory is accurate or not. Figure 3.4 demonstrates the steps associated with the deductive approach compared to the inductive approach.

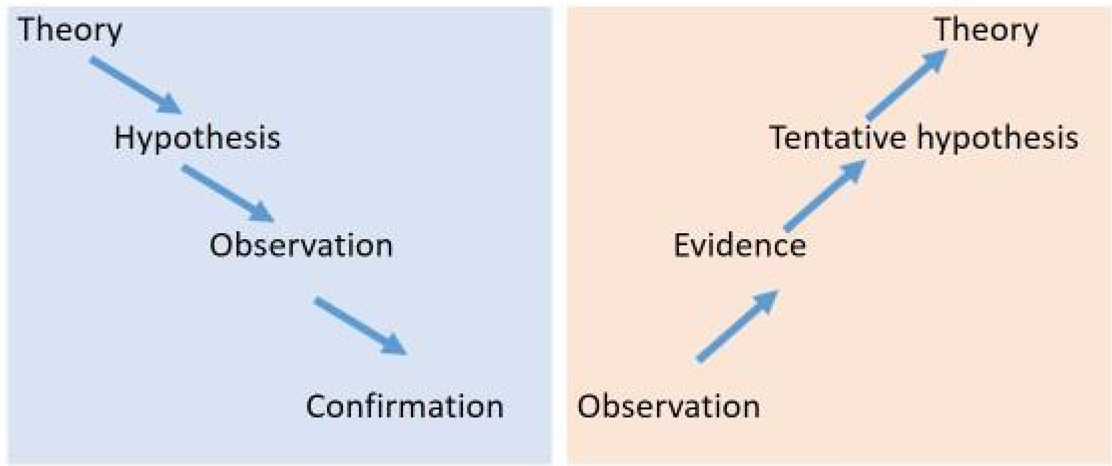


Figure 0.4: Inductive approach compared to Deductive approach.

(Seneviratne, 2015)

The inductive approach can be viewed as open-minded especially at its initial stages, whereas the deductive approach is more closed and narrower and is usually adopted for the confirmation of a theory. Most researchers have both approaches within their research process (DeGracia, et al., 2014). Through a normal research process, finding logical reasoning usually consists of going back and forth between the theory and the research itself, hence this clarifies the differences between the deductive and inductive research approaches and why during research, researchers use both approaches (Saunders, 2009)

3.5.3. ABDUCTION APPROACH

The abduction research approach is neither followed by just the deductive approach nor the inductive approach, having a mixture of these two approaches may produce a more substantial result, the abductive approach can be creative and instinctive, Mitchell (2018) argues using the abduction approach allows the weaknesses found in both the inductive and deductive approach to be addressed (Mitchell, 2018). The abduction approach takes incomplete observations from real life to obtain the most accurate prediction of the truth and hopefully produce a new theory. Within the abductive approach, the start of the research usually starts with unknown facts and puzzles which allows the researcher to figure out their explanation, a range of theories may be explored, and following that the researcher would then choose the best answer from the varieties explored (Awuzie and Mcdermott, 2017).

For this research, an inductive research approach is adopted, using inductive reasoning will assist the researcher in understanding the adoption process of Industry 4.0 strategies within the UK Infrastructure sector and understanding the scale of awareness of the technologies associated with

Industry 4.0 within organisations. This process will begin by gaining an understanding of the respondent's views and opinions to launch a theory that explains Industry 4.0 strategies in the UK Infrastructure sector. The research process then allows the testing and confirming of the relationship between Industry 4.0 strategies and their theoretical benefits and benefits that have been confirmed. The use of the inductive approach will allow qualitative paradigms to be explored (Kovács and Spens, 2005).

3.6.RESEARCH METHODOLOGY

Within a research methodology, two main approaches can be adopted. The first approach was developed by Saunders (2009) (Saunders, 2009), Saunders's approach is represented by different layers which form the "research onion". The second research approach is known as the nested approach and was developed by Kagioglou, in 1998 (Kagioglou, et al., 2000), this approach uses several techniques and tools to narrow and filter down the appropriate research paradigm. Newman and Benz (1998) describe a quantitative study as a research method that is generally used within social research (Newman and Benz, 1998). Conducting quantitative research is very critical within an investigation if it is of a science topic such as chemistry, mathematics, and physics as it provides a school-for-thought approach. Quantitative research is mainly conducted with the use of experiments, archival research, and case studies (Saunders, 2009). Quantitative research is utilising measurement, it is focused on gathering numerical data from a variety of people to justify a specific phenomenon (Babbie, 2010). Qualitative research is carried out not only by academics but also within the professional field as it is more interpretive and allows the researcher to gather diverse data from the participants where a variety of data on the phenomenon can be collected (Ritchie, et al., 2014). The term "Qualitative research" refers to the technique of data collection where the data collected is of the non-numerical form (Yin, 2015), McKinley (2015) argues that qualitative research for action research is key as it provides a strong qualitative content which allows the researcher to obtain more in-depth information, despite qualitative, of the phenomenon (McKinley, 2015). Within a mixed-method research approach, quantitative and qualitative research methods are combined and incorporated into the research design process. This means that at the initial stages of the research, the researcher could adopt an objectivist philosophy, then follow on to a subjective philosophy, or in other cases the researcher can adopt philosophies the other way around (Teddlie and Tashakkori, 2012). In some cases, the researcher uses technics such as quantitative to analyse data already collected which were qualitative, for example after conducting in-depth interviews, the researcher can use statistical analysis to determine the frequency of occurrence within the data obtained from the interviews and observations, this can be conducted the other way around where qualitative techniques are used to analyse quantitative data. This is known as the mixed method complex design (Creswell, 2007), (Saunders, 2009).

This study focuses on the assessment of Industry 4.0 strategies within the UK infrastructure sector. As briefly mentioned previously, there is limited literature available on industry 4.0 relating to the infrastructure sector. In addition, there is a need to gain a deeper understanding of the topic with the limitations of the literature available. It has been argued by Yang et al (2020) that the nature of qualitative research does not require a mass number of participants compared to quantitative research which falls in line with this research study as there are limited people within the infrastructure sector that understand the nature of Industry 4.0.

3.7.RESEARCH STRATEGY

Saunders (2009) introduced the Research onion, within the research onion, one of the layers reveals the strategies. This layer highlights how the researcher can utilise more than one strategy within their research design while answering the research questions. The research strategies demonstrated consist of "Experiment" research strategies, this is very widely used and considered to aid in reducing the number of different outcomes to gain (Trochim and Donnelly, 2006). Experimental research is usually associated with quantitative research approaches and is usually adopted within a positivist research context. Within a welldesigned experimental research approach, a controlled and artificial environment is created to match the events for the research with the elements which would normally go together. The second layer presents a "survey" strategy that is normally adopted where the outcome is extracted from data from a population (Saunders, 2009). A survey strategy is normally set with the use of a questionnaire or a structured interview which is used to gather data to extract patterns between variables (Bryman, Social Research Methods, 2016). Thirdly, a "Case Study" research strategy where case itself can vary where it can be a person, organisation, project etc. adopting case study research can mean that multiple cases can be researched, and finally "Theoretical" research strategy where the strategy is based around a theory explaining the phenomenon. For this study, a grounded theory research strategy is most suitable. The grounded theory approach was initially introduced as a form of strategy to enable the understanding of social research, this strategy uses qualitative methods to further develop a theory. There are key aspects of the grounded theory strategy which are to be considered when a ground theory is adopted which has been highlighted by Saunders (2009) listed below:

- Data collection commences early.

- Collection of data and analysis of data in parallel (e.g., upon completion of one interview, the data was analysed before conducting the next).
- The identification of codes and themes from the data while being collected and going through analysis.
- Constant comparison of the writing to create conceptualisation and devise a theory.
- Adoption of theoretical sampling and theoretical saturation to build on a theory instead of attaining population delegates.
- The use of the literature to support the categories and themes identified in the data.
- Developing a theory based on the data that is grounded.

Mbambo (2013) has noted that with the adoption of the grounded theory, researchers can improve on the theory research gap as the grounded theory mostly uses an inductive approach meaning that the researcher does not need to start with a hypothesis of the topic but has an open approach to what theory presents itself from the data collected (Mbambo, 2013).

3.8.RATIONALE FOR DATA COLLECTION STRATEGY AND DATA ANALYSIS

This study began with a systematic literature review (1) which was used to collect secondary data. Following this, semi-structured interviews (2) were undertaken for the primary data collection. The qualitative data analysis was analysed using Thematic analysis (3) Finally, to create the maturity model (4); TISM (5), Fuzzy MICMAC (6) and GTMA (7) were used to gain a more in-depth analysis of the findings identified during the thematic analysis, these are all expanded on below.

3.8.1. SYSTEMATIC LITERATURE REVIEW

This study uses a systematic literature review, this is a widely used form of approach within a variety of studies. A systematic literature review allows the researcher to use a transparent process which reduces bias within the research as multiple filtered sources are explored allowing extensive exploration of research (Sarrakh, et al., 2021). A systematic literature review differs from the traditional general review as it allows a replicable and transparent process where insight can be gained on the existing studies based on theory. Previous studies have adopted this form of review and have been received well within these previous studies (Reim, et al., 2015). The steps that were followed during the systematic literature review process are presented in Chapter 3 in Section 3.9.

3.8.2. SEMI-STRUCTURES INTERVIEWS

Interviews are appropriate for research if the researcher needs to collect in-depth information on people's opinions, thoughts, feelings, and experiences surrounding a specific topic (Kumar, 1987). According to Adhabi et al (Adhabi and Anozie, 2017), there are three main types of interviews; (1) Structured, (2) Semi-structured and (3) unstructured, the main differences between these types of interviews are what type of power the interviewer has on the interview. It has been recognised by analysts that qualitative interviews always have a structure (Jamshed, 2014), however structured interviews are under the full control of the interviewer and provide less flexibility to the interviewee (Adhabi and Anozie, 2017). Unstructured interviews can be described as conversations that are based on the interviewers' interest, there are a variety of different forms of unstructured interviews which include nondirective interviews in which case the researcher is usually unprepared with no pre-planned questions, another form of unstructured interview is a focused interview in which the researcher is a bit more prepared and they manipulate the conversation to discuss the topic of interest for the research (Jamshed, 2014), unstructured interviews have an irregular structure however they are still an important method of collecting qualitative data. Semi-structured interviews were chosen as the best fit for this study as it presents a structured interview but also allow the participants to explore outside of the structure presented allowing more of a conversation. This allows the participants to share more and the researcher to gain more insight outside of the structure scope that may have not been included within the structure of the interviews.

3.8.3. THEMATIC ANALYSIS

Braun and Clarke (2016) noted that thematic analysis is an introductory method within qualitative research (Braun and Clarke, 2016). Thematic analysis aims to identify the patterns within the collected data which the research conducts through coding the qualitative data gathered for a more in-depth analysis. The thematic analysis allows the consistency within data to be identified and allows the researcher to demonstrate low levels of interpretation hence allowing the researcher to base the analysis on purely the data collected (Vaismoradi, et al., 2013). This study uses thematic analysis as it offers a flexible yet uncomplicated approach to analyse the collected qualitative data. Saunders (2009) noted that thematic analysis allows the researcher to present the qualitative data analysis in an orderly manner which is not viable with the use of other analysis methods, the analysis method is also not filtered to a certain research philosophy which suits the ideology of the nature of this study (Saunders, 2009). This allows themes to be identified from the collected qualitative data and thematic analysis can be used for both larger and smaller sets of data allowing a rich description and justification of the data being analysed. The steps associated with the thematic analysis are analysed further in Chapter 3, section 3.9.

3.8.4. MATURITY MODEL

The infrastructure sector is a very competitive sector which drives organisations to explore views beyond what they currently adopt to stay competitive within the market, thus organisations within the industry need to evolve and improve their strategies and capabilities to ensure that their competitiveness is at an advantage and asses their maturity models (MM) (Barge-Gil and Modrego, 2011). Asah-Kissiedu et al (2021) argue that it is vital for organisations to assess organisations processes and practices to improve their performance, furthermore, capability maturity models (CMM) can be used by organisations to use as a reference framework as they can guide to organisations of measuring and improving their maturity effectively (Asah-Kissiedu, et al., 2021). Concerning Industry 4.0 strategies, a maturity model (MM) can be considered as a tool to describe and assess organisations' processes concerning the environment, economy, and society, in addition, this allows them to better compare the best practices within their organisation and externally with competitors. Lin and Wang (2021) argue that in terms of smart technology, there is a gap between MM and project management where a MM can allow organisations to assess the different levels of efficiency, project management, organisational management, and improvement of processes to enable the overcoming of their weaknesses allowing the promotion of smart transformation (Lin and Wang, 2021), Hence this study adopts the Maturity Model too allow the understanding on what level organisations in the UK infrastructure are in terms of industry 4.0 strategies implementation. This can allow the understanding of what plans to put in place to gain a higher level of maturity within this field.

3.8.5. TOTAL STRUCTURAL MODEL

The total structural modelling approach has an interpretive nature where the opinions of experts establish how the different identified aspects are connected and why they are connected in that way. Total Structural Modelling (TSM) is a modelling method which helps the researcher in establishing an interpretation directly and transitive links by introducing a digraph model (Ruben and Varthanan, 2019). The establishment of these links allows an accurate understanding of the interrelationships between the identified factors instead of the factors being described separately. This methodology takes on the principles from graph theory where the relationship between factors is established in nodes and links. The nodes represent the different factors identified while the links present the contextual relationship between the identified factors (Talib and Rahman, 2019). Rajesh (2017) however argues that within an interpretive structural model (ISM), the interpretations of the links can be deemed comparatively weak as it lacks the capability of assisting in the decision-making and requires a more in-depth interpretation to overcome this disadvantage (Rajesh, 2017). In this study, to overcome this disadvantage, an “interpretive matrix” has been developed to present the interpretations of the relationships of the identified factors that drive organisations to implement Industry 4.0 agenda, which are, Increased Finance and performance, Increased Productivity, Innovation, Competitiveness, Government laws, and Client Demand. This has been integrated with the Total Structural Model to produce a Total Interpretive Structural Model (TISM) (Ruben and Varthanan, 2019) which has allowed the illustration of the relationships between the drivers that have been identified which is vital for organisations to understand as each key driver may influence other key drivers which can alter the vision and goals of an organisation.

3.8.6. FUZZY MICMAC

The Fuzzy MICMAC analysis method enables more precise values of relationships to be determined as the ISM presents a binary relationship (Malviya and Kant, 2017). Duperrin and Godet (1973) developed the Fuzzy MICMAC to tackle complicated systems. In this study, the TISM approach was used as a source of input for the Fuzzy MICMAC analysis which enabled the factors identified to be classified. A traditional MICMAC analysis considers binary relationships between factors which are indicated by the values 0 or 1. Due to the values of a binary relationship, this shows that all relationships are equal which is not always the case and cannot be as all relationships cannot be equal. Therefore, the Fuzzy MICMAC was used to defeat this disadvantage to analyse the relationships of the factors further, this approach was chosen as it enables the researcher to distinguish the relationships and analyse how each factor impacts the other which allows the audience of the research to understand these relationships and implications. The relationships were further analysed to establish relationship strengths between the factors instead of just the existence of a relationship which was demonstrated in a binary form. The Fuzzy MICMAC was used in this study as identifying which cluster the key drivers fall when it comes to implementing industry 4.0 strategies can be crucial information for organisations within the UK infrastructure sector. This can allow decision makers within the organisations to prioritise the key drivers based on their dependence and driving powers.

3.8.7. GRAPH THEORETICAL AND MATRIX APPROACH

Decision-making is an important process within organisations throughout industries as organisations face different situations which can be completely different (Jayawardena Willis, et al., 2019). Therefore the decision-making within organisation’s must be evaluated and solutions are to be identified based on the organisations' vision and values, in addition different parties and teams within organisations may introduce multiple of solutions where one is to be chosen, this research assessed several decision-making processes such as Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), Technique for Order Preference by Similarity to Ideal Situation (TOPSIS), and Graph Theoretical Matrix Approach (GTMA).

The Graph Theoretical Matrix Approach (GTMA) contains the ability to model interactions and structure out challenges. There are many approaches to conducting decision-making that the GTMA enables such as the Analytical Hierarchy Process (AHP) which uses fuzzy data to compare challenges; Kayakutlu and Buyukozkan (2011), Analytical Network Process (ANP) which was used to assess performance factors; Buyukozkan (2011) and Technique for Order Preference by Similarity to Ideal Situation (TOPSIS) using fuzzy data to select a strategic alliance partner; Dereli et al (2010), however the GTMA has been extensively used for quality management modelling, risk management modelling, just to name a few. In this study, the GTMA has been adopted to assess the challenging factors when implementing industry 4.0 strategies. Other methods have been considered such as the AHP and the TOPSIS however both do not allow relationships to be established between factors despite TOPSIS being known as a simple method of decision-making. Without a relationship being identified, the importance of each factor is not possible to be identified.

3.9.RESEARCH STEPS

This research has been split into 4 stages; ***Stage 1:*** systematic literature review; ***Stage 2:*** data collection; ***Stage 3:*** data analysis, and: ***Stage 4:*** the development of a framework and business models for industry 4.0 strategies implementation in the UK infrastructure sector.

Figure 3.5 presents the research process which was followed for this study.

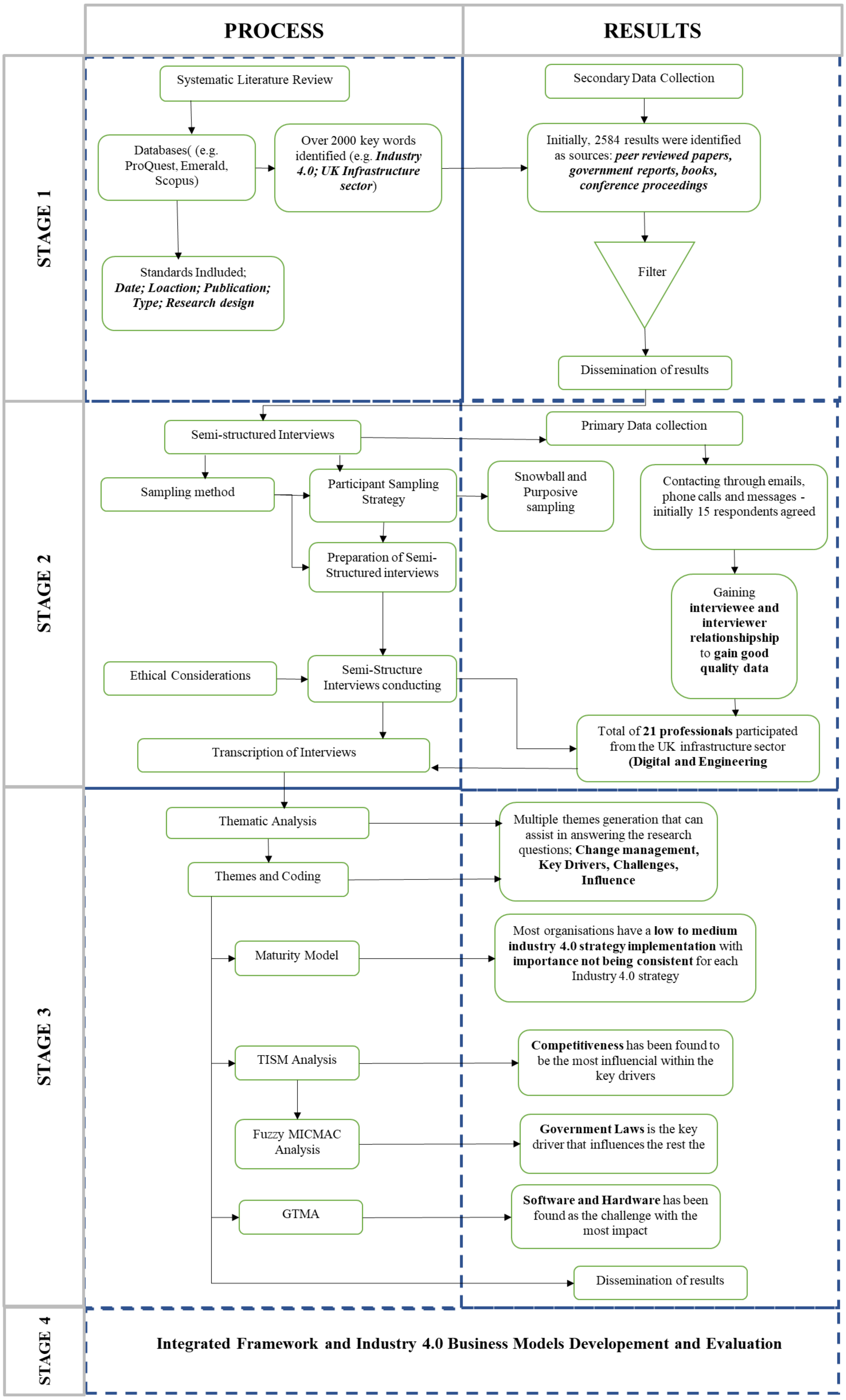


Figure 0.5: Research process

3.9.1. SYSTEMATIC LITERATURE REVIEW

This study utilises a systematic literature review as opposed to a traditional method of literature reviews. The systematic literature review was conducted by qualitative data analysis from the available literature resources to provide an interpretation of the UK infrastructure sector's current industry 4.0 strategies. During the planning stages the research team developed publications which were reviewed, the panel included both members of professional and academic backgrounds as proposed by (Kitchenham, et al., 2009). The first phase included regular discussions and meetings where the contents that should be taken into consideration for the study were discussed and agreed upon, these enabled questions proposed by both academics and professionals on what would be of interest to both parties.

The steps of the systematic literature review are described below:

Table 0.1: Process of the systematic literature review

Phase 1 – Planning of the review	
Step 0	Recognising the need for a review
Step 1	Formulation of a review proposal
Step 2	Review protocol development
Phase 2 – Conduction of the review	
Step 3	Research identification
Step 4	Studies and research selection
Step 5	Assessment of Study and research quality
Step 6	Extraction of data
Step 7	Synthesis of data
Phase 3 – Reporting and transmission	
Step 8	Documenting and proposal
Step 9	Using data in practice
Step 10	Updating review as research progresses

3.9.2. REVIEW QUESTIONS FOR LITERATURE REVIEW

Research questions are a vital part of the literature review, where having a set guide allows the researcher to focus purely on the topic of study within the scope (Dinter, et al., 2021). Research questions that have been poorly defined lead to a risk of the research being a time-consuming process as there can be too much information where they may be deemed irrelevant for the study, hence having a non-systematic review. Consequently, it is a necessity that the researcher clarifies the research questions to allow for a successful systematic approach. Dinter et al (2021) assert that to achieve a systematic review successfully, the researcher needs to define sub-categories of the research questions which can allow the questions to become more tailored to a specific topic.

For this study, the PICO (population, intervention, control, and outcomes) model was used to achieve the clarification of the sub-categories. This was developed to guide research questions to formulate the literature review. The PICO model aspects are described below:

- **Population (P):** *What is the target population for the researcher to study?* This involves the identification of the target population that is suited to the study.
- **Intervention (I):** *What is the target intervention the researcher aims to review?* Depending on the approach of the researcher, this can be either multiple or singular interventions.
- **Comparison (C):** *What is the intervention being compared to?*
- **Outcome (O):** *What is the anticipated outcome expected by the researcher through the chosen intervention?* The relevant outcomes definition is crucial to make certain that the information collection is conducted efficiently.

Table 3.2 maps this research's literature review questions to the PICO model:

What are the key 'Industry 4.0 strategies' that are currently being adopted within the infrastructure sector?

Table 0.2: PICO model defined.

Model Acronym	**Acronym definition**	**Description**
P	**Population**	UK infrastructure sector
I	**Intervention**	Organisations and Government
C	**Comparison**	UK's position before Industry 4.0 implementation.
O	**Outcome**	The country and sectors innovation performance

3.9.3. RELIABILITY OF THE DECISION

An inclusion of members of academics, infrastructure background and engineering from the infrastructure sector were gathered to form a panel. During this panel, the inclusion standards were set, and the sources were reviewed to analyse whether they should be included or excluded. The reviewers selected reviewed each of the articles and sources to verify their relation to the infrastructure sector and industry 4.0 strategies. This process has been undertaken by Sanchez-Lopez et al (2021) in their study of tactical knowledge (Sánchez-López, et al., 2022).

For this research study, the review was centred around journal articles from the following data platforms: Directory of Open Access Journals, Scopus, ProQuest, SpringerLink, Elsevier and Scholar. Additionally, government and organisation reports were included in the selection of articles due to the nature of this study. The criterion of what has been included or excluded for this study is demonstrated in Table 3.3.

Table 0.3: Resource Criteria for Inclusion or Exclusion

	Inclusion	**Exclusion**
Date	2010 – 2022	Before 2010
Location	UK	
Language	English	Papers in other languages
Type	Research papers, articles, and books	Book reviews, notes, and research thesis
Publications	Organisation and government reports, published books, peer-reviewed journals, and articles.	Papers focussed on industrial topics
Participants	Organisations in the UK infrastructure sector	
Design	Case study, qualitative, and theoretical studies	Papers with no structure or data or research process

Focus	Does the study examine UK's infrastructure sector and Industry 4.0 strategies? Does the study include Industry 4.0 strategies within the UK infrastructure sector?	Studies with no link to Industry 4.0 strategies

3.9.4. KEYWORD PRODUCTION AND ANALYSIS

During the panels and meetings, the members included in the panels assisted in identifying the keywords relevant to the study based on experience. The keywords were gathered and listed which were grouped in order of relevance. There were 16 keywords identified and the categories of these keywords were specific to industry 4.0 policies, keywords relating to the infrastructure sector, and performance of innovation. The keywords selected were, UK Industry 4.0 development; Infrastructure sector; technology-based policies; Industry 4.0 development; Industry 4.0 goals; UK's economic development; UK's environmental development; UK'S social development; Industry 4.0 performance; Infrastructure sector performance; Infrastructure sector digitisation; Infrastructure sector Automation; Knowledge management; Industry 4.0 development practices; industry 4.0 management; and UK's digital vision.

3.9.5. SEARCH DEADLINE

A timeframe was set for the commencement of the literature review process to enable the tasks for the process to be scheduled. The target dates were set together with the panel members selected. Table 3.4 details the duration of each task conducted during the literature review process. Appendix A provides an exemplar of the review protocol which was used.

Table 0.4: Systematic literature review process and Timeframes

Period (weeks)	**Stage**
4	Formulation of the review protocol
12	Exploration of the relevant studies
6	Assessment of Inclusion in the Studies
10	Data collection

7	Analysis of data
6	Documenting and dissemination

3.9.6. DATA COLLECTION STRATEGY AND ANALYSIS

DATA EXTRACTION

To allow easier data analysis, the data extraction process was undertaken by using Microsoft Excel which was made available on OneDrive where the link was shared. The researcher added relevant data extractions where it was easily presentable due to the format allowing for easier summarisation and analysis. Appendix B demonstrates an example of the form used for data extraction.

The data collected from the literature review uses thematic analysis to identify the patterns and relationships from the different studies that are relating to the same topic. Each study was analysed and coded based on the research questions to compare the results. The data analysis allowed the themes across industries relating to Industry 4.0 to be highlighted and noted. Additionally, due to the adoption of a systematic literature review, the data was quantitative, and a meta-analysis approach was adopted. This allowed the author to statistically combine the results from a variety of authors where the themes, patterns and relationships were identified. It was noted by the researcher that there was a major lack of research on industry 4.0 strategies concerning the infrastructure sector. However, BIM for construction has been highlighted as the Industry 4.0 strategy that has been the main adopted strategy within the infrastructure sector.

The literature also highlighted challenges being faced within the sector, namely resistance to change and organisation culture. The literature has shown that organisations have gained benefits through Industry 4.0 adoption such as better planning and productivity, these results are further discussed between Chapter 5 – Chapter 9.

DATA COLLECTION

The validation of the theoretical framework began with semi-structured interviews being conducted with seven case studies to reflect the status of Industry 4.0 within the infrastructure sector. The stages that were undertaken to collect the qualitative data have been discussed within this section. The interviews were collected over six-months between January 2021 and June 2021. The interviews were between fifteen to thirty minutes each. 21 experts participated in Semi-structured which included BIM Leads, Head of BIM, Digital Leads, Engineers, and Surveyors all with a minimum of three years' experience within the UK infrastructure sector, the list of participants is demonstrated in Table 3.5 and Table 3.6 highlights the overview of the organisations.

PARTICIPANT RECRUITMENT STRATEGY

The recruiting of participants for research is a crucial step and can determine the success of the research. Tinker et al (2017) have stressed that despite there being high importance for a participants recruitment strategy, studies are still lacking the availability of a proper strategy which affects the research in terms of the availability of suitable participants or overestimating the number of participants (Tinkler, et al., 2017). This study adopts a recruitment strategy where organisations have been targeted that is suitable for this study and the potential respondents were emailed as a first contact. An email draft was produced and presented in Appendix C, following this, the interviews were then conducted with either a phone call or Microsoft Teams call.

Table 0.5: Classification of the Interviewees

Interviewee	Assigned Number	Profession	Organisation	Years Experience
Interviewee 1	PARE1	BIM Lead	Organisation E	>9
Interviewee 2	PARE2	Head of BIM	Organisation A	>15
Interviewee 3	PARE3	GIS manager	Organisation C	>4
Interviewee 4	PARE4	BIM manager	Organisation B	>3
Interviewee 5	PARE5	BIM manager	Organisation E	>6
Interviewee 6	PARE6	BIM Lead	Organisation B	>9
Interviewee 7	PARE7	Head of Digital and Technical Assurance	Organisation D	>16
Interviewee 8	PARE8	BIM manager	Organisation D	>13
Interviewee 9	PARE9	BIM Lead	Organisation A	>20
Interviewee 10	PARE10	Survey Manager	Organisation A	>5
Interviewee 11	PARE11	Site Engineer	Organisation F	>6
Interviewee 12	PARE12	Utilities Coordinator	Organisation F	>4

Interviewee 13	PARE13	Project manager	Organisation F	>17
Interviewee 14	PARE14	Site agent	SandM Organisations	>4
Interviewee 15	PARE15	Senior Design Manager	SandM Organisations	>12
Interviewee 16	PARE16	BIM Coordinator	Organisation C	>5
Interviewee 17	PARE17	Design Manager	SandM Organisations	>8
Interviewee 18	PARE18	Quantity Surveyor	SandM Organisations	>3
Interviewee 19	PARE19	Site Engineer	SandM Organisations	>8
Interviewee 20	PARE20	Site Supervisor	SandM Organisations	>21
Interviewee 21	PARE21	Site Supervisor	SandM Organisations	>12

Table 0.6: Overview of Organisations

Organisation	No of Employees in the UK	Location	Nature of business
A	5,300	Global	Housing and infrastructure assets construction
B	20,000	UK	Construction and infrastructure (Roads and Rail)
C	3,500	UK	Water, Nuclear Process and Oil and Gas and Infrastructure which include Highways, Rail and Power
D	26,000	UK	Education, roads, street lighting, renewables
E	71,000	Europe	Landscaping, railway structures, bridges, tunnelling, and roads
F	6,700	UK	Construction and infrastructure, Property services, urban generation

S&M	300 max	UK	Infrastructure assets (Drainage works, landscaping, Paving, Reinforcement, Surveying)

SEMI-STRUCTURED INTERVIEWS PREPARATION

Within research, preparation is key to safeguarding its success. The five Ps were introduced by Saunders (2009) and was implemented in this study to ensure that the semi structured interview preparation was done correctly five P's states: Prior Planning Prevents Poor Performance. To ensure that the quality of responses was good, a few steps were undertaken in preparation for the data collection from the semi-structured interviews. Initially, enough knowledge was gathered on the research topic through conducting a literature review. In addition to this, each organisation that was targeted for this study was investigated gathering information from their annual reports and publications. This allowed the researcher to encourage the participants to be more open during the interviews and provide more detailed data. Secondly, following the agreement of the interview with the participants, the participants were asked for a general list of the themes throughout the interview. This raised that some participants lack knowledge on some of the themes which limited the researcher where the researcher acted and provided research information before the start of the interviews. The main themes that were proposed to the participants were derived from the research questions and aims of the study. This also allowed a guide to be drawn in terms of the interviews. The interviews were all conducted via phone calls or Microsoft Teams calls in the UK due to the interviews taking place during COVID-19.

CONDUCTING SEMI-STRUCTURED INTERVIEWS

The first impression of the researcher that is taken by the participants is vital for a study. Saunders (2009) argues that having a good impression of the researcher by the participants can enable them to gain confidence and assures them of their credibility. For this study, not all the participants were known by the researcher beforehand, therefore it was of great importance that the researcher explained the research to gain credibility from the participants and their trust. In addition, organisations within the infrastructure sector work with sensitive information, thus the researcher provided all participants with an information sheet and consent form which are both provided in Appendix D. Within the information sheet and consent form, it is described how the collected data will be treated and what would happen beyond the completion of the research. During the initial discussion, the participants were asked general questions about their roles and an overview of their knowledge of Industry 4.0 strategies based on their knowledge. After that, the research questions identified on the themes generated were asked, such as Industry 4.0 strategies already implemented within their organisations, the key drivers that have fuelled that, the challenges that are blocking Industry 4.0 strategies implementation and how their organisation is implementing change management to assist with industry 4.0 strategies implementation. All interviews were conducted in English, the interview questions are available in Appendix D. Moreover, open-ended questions were presented to allow the participant to provide more information and avoid bias, for questions that required a specific point to be made, specific questions were asked on the topic. All interviews were recorded using the Microsoft Team meeting recorder feature, additionally, notes were made during the interviews as a form of backup. The recordings were then transcribed, and the analysis followed the ground theory strategy.

SAMPLING METHODOLOGY

Sampling is a key factor within research, the sampling size is to take into consideration the accuracy that s required and acceptable for the study being undertaken. A sampling frame is necessary to compile the represented responders (Knight and Ruddock, 2008). For sampling for research, the objectives of the research study first need to be identified to allow the target of the right sample audience and sampling size. Conducting qualitative studies, Creswell (2016) has stated that between twenty and sixty interviews should be sufficient for a grounded theory-based research study. Mason (2010) analysed 560 PhD students and agrees with Creswell as with their main method being qualitative research, it was found that their sample size varied between fifteen and fifty participants with the average sampling size being twenty for grounded theory studies (Mason, 2010). This study adopts purposive sampling as the sampling technique. The UK infrastructure sector is a sensitive sector, due to its sensitivity, the snowball sampling method was also explored. The sampling size was determined based on the saturation of data being collected, where the themes and information became repetitive during the data analysis the interviews were stopped.

ETHICAL CONSIDERATION

For this research study, an ethical approval form was completed by the lead researcher and passed to the research supervisor to be submitted for approval to the ethics committee of the institution within the School of Architecture and Built Environment, Faculty of Science and Engineering at the University of Wolverhampton before the commencement of the interview process.

The interviews were recorded on the virtual platform they were conducted and transcribed to provide a literal transcript. The transcribed interviews exclude factors such as laughter, changes in voice tone and any other nuanced behaviour.

3.9.7. DATA ANALYSIS

This section describes the data analysis methods used in this study. Thematic analysis was adopted to analyse the collected data from the interviews where the themes were identified and explored in-depth with the use of the following methods: TISM, GTMA, maturity model and Fuzzy MICMAC.

THEMATIC ANALYSIS

This study adopts thematic analysis, and the grounded theory strategy was used where the data being collected was analysed as the researcher was still conducting interviews and collecting data. Through the transcription of the data, while collecting data, the researcher gained an understanding of the data being collected as the data transcription process takes time, this allowed the researcher to become familiar with the themes as the data collection process was still ongoing. This stage was vital as it allowed the researcher to identify the themes during the data collection process. The collected data and identified themes were then coded to enable easier and simpler data management. The allocation of participants' numbers was done as follows: Participant Response + Participant Number → PARE#; for example, the file which is relating to the sixth participant was given a code PARE6. The coding of data is a vital part of qualitative data analysis as it allows the cluster of similar or the same information, this process involves the labelling of the data with an assigned code which represent that they have the same meaning. For this study, the labelling unit used where phrases as the participants discussed a variety of topics at the same time. This step allowed the researcher to identify the themes and patterns in the data collected where data with similar meanings were grouped, each code was defined to ensure there is consistency. The software used in the coding process was Nvivo 12 which aided in the thematic analysis where the themes were represented by a variety of similar codes. This allowed the researcher to identify the main themes which are concerning the study. This was a crucial part of the research as it enables the research questions to be answered, for example, Key drivers motivating the implementation of Industry 4.0 consist of Government Laws, Client Demand, and Innovation. The themes were then evaluated to ensure that they are relevant to the research study, this was conducted through many different data analysis methods to allow the research questions to be answered.

MATURITY MODEL

A Capability Maturity Model (CMM) was developed in this study to assess organisations' process development allowing the highlighting of the necessary steps to improve traditional practices. The CMM is made up of five levels which have been used for this study and were introduced by Tivtov et al (2016) described as follows:

- ***Initial:*** The initial level, sometimes known as chaotic, focuses on the standardisations of the organisation, knowledge, motivation, and strategic planning, it can be considered as the immature stage where a few processes may be defined but the performance of the business may be poor.
- ***Repeatable:*** This level, also known as the Planned or Tracked level, is said to be an unorganised phase, however, this level demonstrates a planned process to track elements such as costs where the processes are established and can be repeated on other similar projects.
- ***Defined:*** This level demonstrates good practice sharing, at this level, the organisation would have defined training programmes available where processes are being standardised and integrated within the organisation.
- ***Managed:*** At this level, controlled activities are used to enhance the delivery of projects, where processes are being managed and recorded to gain a better understanding of the processes and product.
- ***Optimising:*** The fifth level sometimes known as the continuous improvement level continuously improves the organisation including its processes and change management.

This study restructures the original CMM to be in line with Industry 4.0 initiatives to assess the thirteen organisations' maturity levels. This has been demonstrated and explored in Chapter 6.

TOTAL INTERPRETIVE STRUCTURAL MODELLING

TISM is an extension of the methodology ISM. This method has been used by numerous researchers as it proves to be an efficient process of decision-making (Rajesh, 2017). The TISM combines the opinions of experts, determining the connection between the different identified factors. In addition, the TISM enables complex systems to be modelled by representing them in a simple form of a digraph model that presents the direct and indirect linkages. This methodology aims to present an easily understandable model which aids in answering what, why, and how questions allowing the creation of a theory.

The ISM was developed by Warfield (1974) and Sage (1977) and was then modified by

Sushil (2012) as the ISM lacks clarity of the "how" when interpreting relationships (Sushil, 2012). Sushil (2012) introduced the TISM which is demonstrated in Figure 3.7.

Below are the relevant steps for TISM.

Step 1: Defining and classifying the factors.

The first step within the TISM was to classify and define the different factors within the system. For this study, the methodology chosen to identify these factors is gathering the experts' opinions, both academically and within the industry through focus groups, interviews, and existing literature.

Step 2: Distinguish the contextual relationship.

The determination of the contextual relationships between the identified factors was a crucial part of the TISM, this was heavily dependent on the structure of the system, for example, their influence and importance.

Step 3: Interpretation of the relationships

This next step differentiates an ISM from the TISM where the TISM aims to highlight the root of the identified relationships between the factors by establishing how each factor impacts the other factors, this allows a deeper understanding of the system.

Step 4: Pair-wise comparison using Interpretive logic.

Each factor was then compared to the other factors within the system, where the expert opinion was taken into consideration and each pair-wise comparison was assigned the code "Y" for yes and "N" for no. Once these codes were assigned, each factor that contained the code "Y" was further interpreted.

Step 5: The Reachability matrix and transitivity assessment

Using the codes assigned where “Y” was turned into the number 1 and “N” turned into the number 0, the reachability matrix was produced. Transitivity properties were then added onto the reachability matrix to obtain the final reachability matrix, for example, if factor a influences factor b, and the factor b has an impact on factor c, then a influences c through transitivity, this is demonstrated in Figure 3.6 The major transitive links are explored deeper within this study.

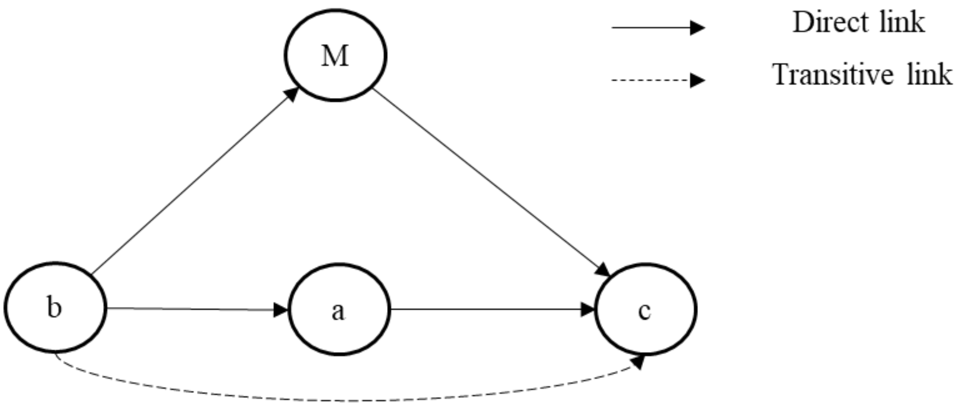


Figure 0.6: Explanation of the transitive concept

Step 6: Level-wise placement

The factors were placed in a level partition to classify each of their level-wise placement. The final reachability matrix was used to determine precursor sets for each identified factor, the precursor set includes the factor itself and other factors that have aided in making it achievable. The reachability set was then created presenting the factor itself and other factors that influenced its achievement. In addition, classifying the intersection of each of the sets of two factors allowed the determination of the intersection set.

In the case that reachability and intersection for factors were similar, these factors were assigned at the highest level of the hierarchy. The factors within the highest level in the hierarchy represented factors that did not influence on the other identified factors that are above their level. The highlighted factors within the top level were eliminated once identified from the remaining factors and the processes were repeated until each factor was assigned a level.

Step 7: Development of the digraph

The results from the level partition were used to develop the digraph, each factor was set in its corresponding levels to derive the direct transitive links between them.

Step 8: Interpretive matrix

The developed final digraph was converted into a binary matrix representing the factors' interactions by the number 1 within their corresponding entries. Each cell that was assigned with 1 was then converted with the use of the interpretations defined in step 7 to create the interpretive matrix.

Step 9: TISM (Total Interpretive Structural Model creation)

The digraph that was developed was then transformed into the TISM by incorporating the interpretive matrix, the nodes identified were replaced with the statements from the factors where the information presented within the interpretive matrix was demonstrated next to the relevant links.

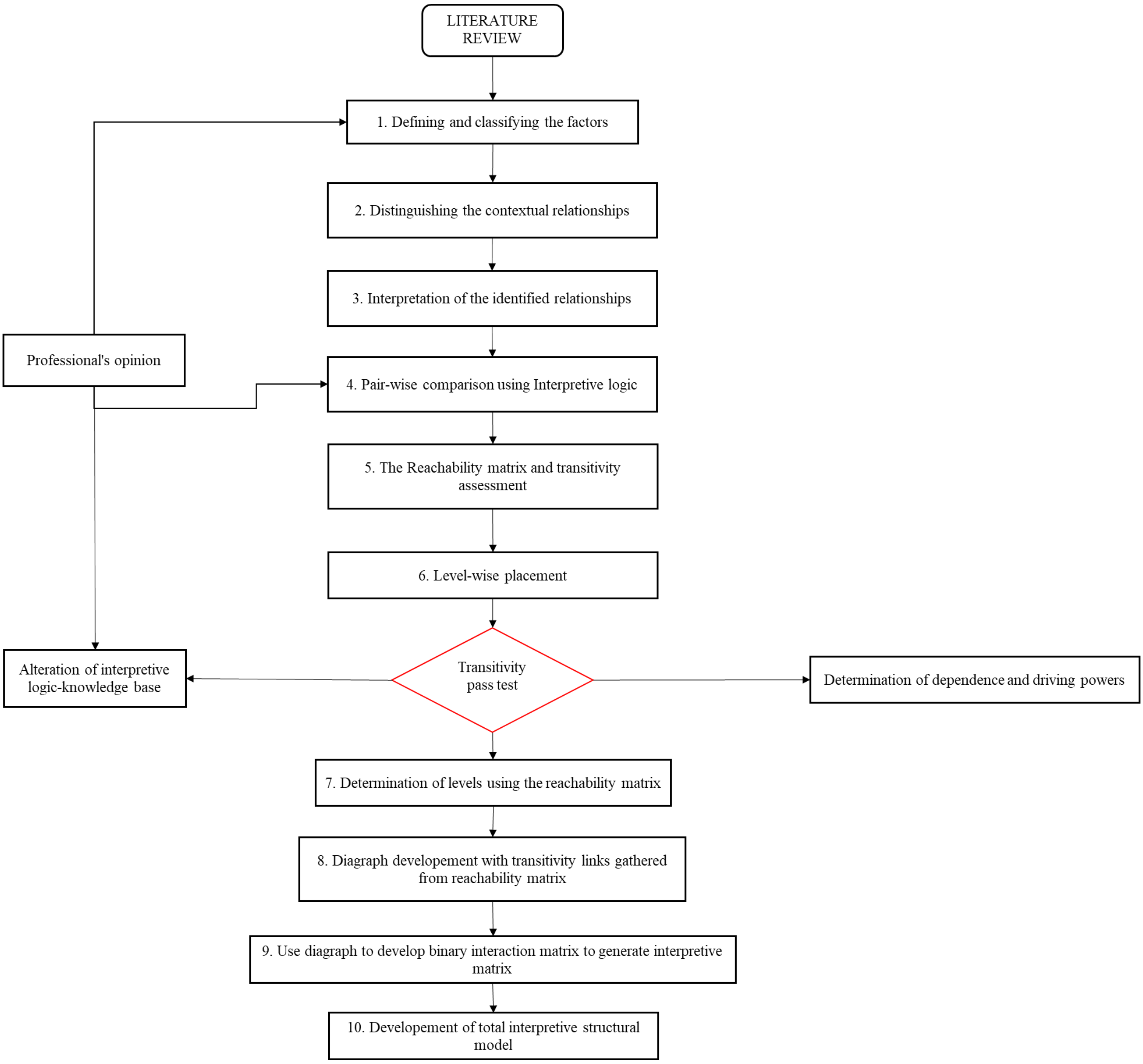


Figure 0.7: TISM preparation workflow

Sushil (2012)

FUZZY MICMAC ANALYSIS

The steps included within the fuzzy MICMAC analysis are detailed below:

- **Creation of the (BDRM) Binary Direct Relationship Matrix**

The direct relationships between the factors within the TISM that were derived from the reachability matrix were evaluated to create the BDRM where the diagonal assigned numbers were converted to 0.

- **Creation of the (LADRM) Linguistic Assessment Direct Reachability Matrix**

The membership function was used to undertake the gradual assessment of the identified factors memberships where within the set, the functions were assigned a value with a realistic interval unit of [0, 1] and are characterized as μ_A (x) as a function demonstrated in Figure 3.8. The function contains three units which are a lower limit demonstrated by l, an upper limit demonstrated as r and a figure demonstrated as m where l < m < r. The membership function μ_A (x) is defined by the definition of the three x vertices and is classified as with the equation shown below:

$$\mu_A(x) = \begin{cases} 0 \\ \frac{x-1}{m-1} \\ \frac{r-x}{r-m} \end{cases} \quad x < 1; \quad 1 \leq x \leq m; \quad x > r; \quad m \leq x \leq r \qquad (1)$$

The experts' opinions were considered during the development of the linguistic scale to identify the strength of the relationships. The values were inputted into the BDRM with the output of the LADRM.

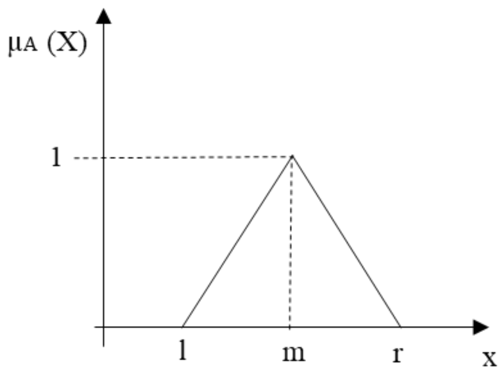


Figure 0.8: Representation of the membership function

- **Defuzzification**

Defuzzification is a required process to convert the fuzzy numbers into matrix operations that can be better used for the analysis. This process allows the development of the fuzzy direct reachability matrix (FDRM). This process converts the fuzzy numbers developed into more accurate numbers; the process has been with the use of the BNP (Best Non-fuzzy Performance):

$$\boldsymbol{BNP_{ij}} = \frac{[(\boldsymbol{r}-\mathbf{1})+(\boldsymbol{m}-\mathbf{1})}{\mathbf{3}} + 1 \quad (2)$$

- **Fuzzy MICMAC stabilised matrix**

The initial matrix process is known as the FDRM. During this process, the matrix is multiplied on repeat until both driving, and dependency powers become stable. The operations carried out during the multiplication are demonstrated by Equation 3:

$$\boldsymbol{Z} = \boldsymbol{X} * \boldsymbol{Y} = \mathbf{max}\ \boldsymbol{c}[\mathbf{min}(\boldsymbol{x_{ik}},\boldsymbol{y_{kj}})] \quad (3)$$

$$\boldsymbol{Z} = \boldsymbol{X} * \boldsymbol{Y} = \mathbf{max}\ \boldsymbol{c}[\mathbf{min}(\boldsymbol{x_{ik}}, \boldsymbol{y_{kj}})]$$

Where: $\boldsymbol{X} = \boldsymbol{x_{ik}}$ and $\boldsymbol{Y} = \boldsymbol{y_{kj}}$

GRAPH THEORETIC MATRIX APPROACH

The GTMA approach contains the ability to quantify and assesses the intensity of variables as it is a multiple attribute decision-making methodology (Jain and Raj, 2016). This allows multiple relationships to be established between the identified factors. There are three elements associated with GTMA, (1) digraph representation, (2) representation of matrix, and (3) representation of the permanent function. The representation of the digraph allows structure and systems to be established which forms are interpreted by nodes and edges. The nodes identified represent the characteristics measurement of the factors whereas the edges represent their dependence. The permanent function shows the interdependence between the factors due to being represented by a mathematical representation.

- **Representation of the digraph**

The digraph aims to represent the elements within the system as nodes and edges. There are two possible graphs to use during this process, (a) undirected, where the edges do not contain direction representation, and (b) directed, where the edges are directed. The nodes are represented by; N = {$\boldsymbol{n_i}$}, and the edges are represented by; E = {xij} where (ij) = 1, 2, 3……X. The total number of nodes, X, equates to the number of identified factors in the system. In this scenario, the identified node i contains greater importance than node j, hence the directed edge represented by the arrow travels from node i to node j. Figure 3.9 provides an example of the digraph representation.

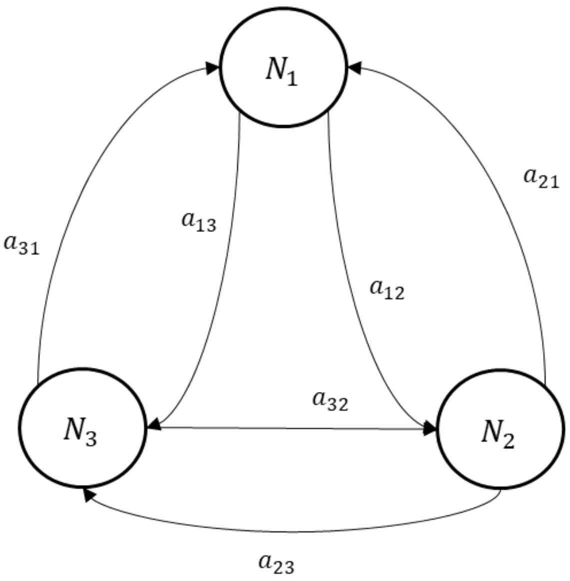


Figure 0.9: Representation of Digraph with a system with 3 factors

REPRESENTATION OF MATRIX

The digraph allows a visual illustration to be visualised, however, this is not processable by computers or mathematical equations. Hence, a system with multiple factors and complex relationships can make the take of understanding the digraph almost impossible. Consequently, digraph must be transformed into a representation that is computable. The incidence matrix proposed by Rao (2007) seemed the best fit for the representation of the digraph (Rao, 2007). Equation 4 demonstrates an example of the matrix representation.

$$X = \begin{pmatrix} C_1 & a_{12} & a_{13} \\ a_{21} & C_2 & a_{23} \\ a_{31} & a_{32} & C_3 \end{pmatrix} \quad (4)$$

PERMANENT FUNCTION REPRESENTATION

The permanent function was introduced in the early 1800s by Binet Cauchy (JURKAT and RYSER, 1966). The permanent function is achieved in the same way a determinant would be, however, the negative values are disregarded. This allows the system to be better appreciated as the negative values not being incorporated will allow minimal loss of information. The permanent function of matrix representation X = (xij) with a M x N matrix, where m ≤ n is demonstrated below (Minc, 1978).

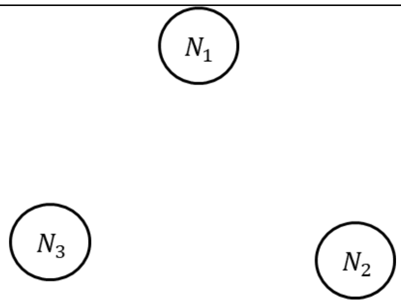
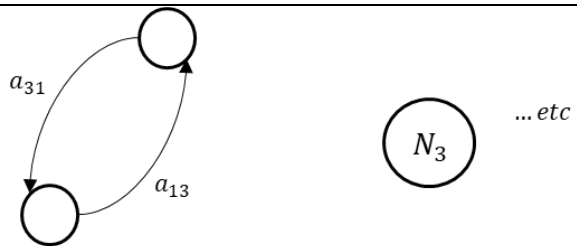
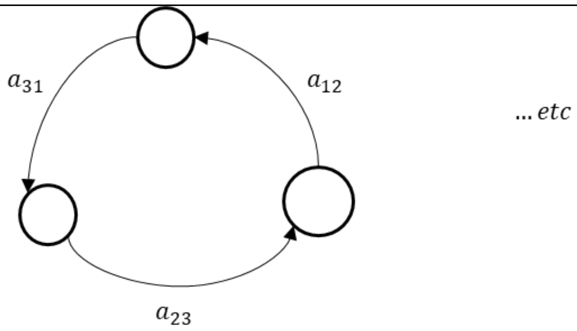
$$Per\ (X) = \sum_{\sigma} x_{1\sigma(1)}\, x_{2\sigma(2)} x_{3\sigma(3)} \cdots \cdots x_{m\sigma(m)} \quad (5)$$

The sum resulting in the permanent function considers all functions {1, 2, 3…., m} up to {1, 2, 3…., n}. The sequences represented by $x_{1\sigma(1)} \ldots \ldots x_{m\sigma(m)}$ is known as the diagonal of Matrix X where the output of $x_{1\sigma(1)} \ldots \ldots x_{m\sigma(m)}$ is known to be a diagonal product of the matrix X. Hence, the permanent function of matrix X is the total of all the diagonal products. An example of achieving the permanent function for matrix A is demonstrated below, this is describing the permanent function in terms of Figure 3.9.

$$Per\ (A) = N_1N_2N_3 + N_1a_{23}a_{32} + N_2a_{13}a_{31} + N_3a_{21}a_{12} + a_{31}a_{23}a_{12} + a_{13}a_{32}a_{21}$$

The matrix representation Per (A) contains 6(3!) terms which are grouped as 4(3+1) demonstrated in Table 3.7.

Table 0.7: Example representing the different terms in permanent function.

Group No	Terms numerical definition	Terms	Sub-graph
1	1	$N_1N_2N_3$	
2	0	-	No loops
3	3	$N_1a_{23}a_{32}$ $N_2a_{13}a_{31}$ $N_3a_{21}a_{12}$	
4	2	$a_{31}a_{23}a_{12}$ $a_{13}a_{32}a_{21}$	

3.10. DEVELOPMENT AND ANALYSIS OF THE INTEGRATED FRAMEWORK AND BUSINESS MODEL

The study findings were used to develop an integrated business model framework for the implementation of Industry 4.0 initiatives within the UK infrastructure sector. The findings which supported this development included literature sources, and each stage's findings from the results. The development of the business model framework was in response to the interviewees who have highlighted that there is a need for a business model framework for the implementation of industry 4.0 initiatives within the sector.

The framework that was developed was assessed by five experts from three different organisations within the UK infrastructure sector with a minimum of 10 years' experience. The framework was emailed to the experts initially to allow the framework to be explored in depth. The interviews for validation were limited to Microsoft Teams due to COVID-19 and interviewees being in different parts of the UK. The interviews were conducted between June 2022 and August 2022. Appendix – contains the interview questions and each interview lasted between fifteen to twenty minutes.

3.11. DEVELOPMENT AND ANALYSIS OF THE INDUSTRY 4.0 READINESS TOOL

The readiness tool was developed similarly manner to the framework. The findings and results with some input from the literature review were used to develop the tool. The tool has been developed to aid in assessing organisations' readiness within the infrastructure sector when implementing industry 4.0 initiatives. The overall score establishes if the organisation is ready for industry 4.0 initiatives implementation or not, in addition, it highlights which aspects need to be enhanced within their organisation to achieve a successful implementation.

To validate the readiness tool, the same process was followed from validating the framework which is defined in section 3.10.

3.12. CHALLENGES DURING METHODOLOGY EXECUTION

The first challenge was encountered during the literature review stage. The research was conducted on a part-time basis where the researcher resides in a different part of the UK to the University of Wolverhampton and worked full-time. Due to this books and resources available at the university library and not online were not accessible to review at times. This was overcome with the support of the supervisory team sending recommended literature that have been reviewed by them which could be purchased and owned as it was already verified that it can add value to this study. In addition, the literature review initially commenced as a critical literature review, as the review progressed, it was noticed that a systematic literature review would be more suited to this study as it covers a broader topic.

The second challenge which was the biggest was getting enough experts within the field of this study to participate in the interviews. There was a lack of experts in the sector for large Tier 1 organisations which were within the targeted audience that was open to participating in the interviews. This was overcome by the snowball sampling where the participant's hunt was expanded to small and medium-sized organisations where they have met the criteria due to being part of the supply chain for the larger organisations. Additionally, this allowed a wider perspective of the infrastructure sector's position in the fourth industrial revolution to be noted which worked out to be more insightful.

The third challenge was minor as it was on the analysis technique selected for the study. Initially, content analysis was considered, however upon review of the qualitative data during the collection stage, thematic analysis seemed to be the better fit for this study as identifying the themes in codes seemed more valuable according to the interviewees. Additionally, analysis methods and tools such as the GTMA and Fuzzy MICMAC allowed the themes identified through the thematic analysis to analyse each different factor. The researcher benefited from gaining assistance from the University of Wolverhampton's supervisory team and colleagues as understanding these analysis methods proved to be difficult.

Finally, the last challenge is related to the recent global pandemic and the spread of COVID19. The researcher encountered multiple challenges as there was a lack of access to attend the university. Additionally with the researchers' full-time career, working from home added additional pressure leading to less time to dedicate to the research. The support from the supervisory team was very helpful during this time.

3.13. SUMMARY

In this chapter, the research methodology has been thoroughly explained, this includes the research techniques chosen to collect and analyse the data. Additionally, it gives an in-depth discussion on the evaluation of the implementation of Industry 4.0 initiatives in the UK infrastructure sector. This study sees a pragmatic philosophy due to its exploratory nature; qualitative methodology was chosen, and an inductive approach was adopted. Several data analysis methods and data collection techniques were adopted such as semi-structured interviews, thematic analysis, GTMA, Fuzzy MICMAC and TISM.

The findings of this study are presented and discussed between Chapter 5 and Chapter 9. The findings were evaluated, and an integrated framework and readiness tool were developed for industry 4.0 initiatives implementation.

CHAPTER 4: SUMMARY OF RESULTS

4.1. INTRODUCTION

This chapter summarises the results gathered from the data collected through interviews to answer the research questions. The chapter is split into five sections, the first section highlights the key drivers that fuel the need for industry 4.0 strategies being implemented within the UK infrastructure sector. These key drivers were analysed using the Total Interpretive Structural Model (TISM) and Fuzzy MICMAC further in this thesis in Chapter 5. The second section identifies the key industry 4.0 initiatives that have been implemented within the UK infrastructure sector which are further analysed in Chapter 6 using the capability maturity model to distinguish what level of implementation the UK infrastructure sector is in terms of industry 4.0 strategies implementation.

The chapter then highlights the key change management strategies that have been implemented to ensure successful implementation of industry 4.0 strategies in the UK infrastructure sector. These change management strategies have further been analysed in Chapter 7 and mapped into Mckinsey’s 7-S model. The following section highlights the key challenged faced within the UK infrastructure sector when implementing industry 4.0 strategies, these challenges are analysed in Chapter 8 to identify which challenge is the most likely to affect organisations using the Graph Theory Matrix Approach (GTMA). Finally, the chapter then highlights the contribution of industry 4.0 strategies that the UK infrastructure have gained. These contributions are further analysed in Chapter 9 using the Triple Bottom Line (TBL) approach.

4.2. THE KEY DRIVERS MOTIVATING OF ADOPTING INDUSTRY 4.0 INITIATIVES

In this study, the key drivers that have fuelled the adoption and implementation of Industry 4.0 agenda were generated from the qualitative analysis thematic approach. Six key drivers were identified and were split into two main groups which are Internal and External drivers. The internal drivers identified were Increased Finance and performance, Increased Productivity, and Innovation. The remaining drivers which were external drivers were classified into three sub-groups: Normative pressure (Competitiveness), Coercive pressure (Government laws) and Mimetic pressure (Client Demand). Table 4.1 provides a summary of the key drivers identified by the interviewees.

Table 0.1: Key drivers that have driven organisations to implement industry 4.0 strategies within the UK infrastructure sector.

Clusters		**Drivers**
External drivers	**Coercive pressure**	Government Laws
	Normative Pressure	Competitiveness
	Mimetic Pressure	Client Demand
Internal Drivers		Increase Finance and performance
		Increased Productivity
		Innovation

The key drivers that push the implementation of Industry 4.0 strategies within the infrastructure sector were highlighted from the data collected and analysed. Furthermore, the relationship between these identified drivers is attempted to be highlighted using Total Interpretive Structural Modelling and the Fuzzy MICMAC approach.

The key drivers that fuel the UK infrastructure sector to implement industry 4.0 strategies were identified through thematic analysis of the qualitative data collected using a metatheoretical lens based on resource and institutional views. Six key drivers were identified and were split into two groups, the Internal drivers, and External drivers. The internal drivers include Coercive Pressure (Government laws), Normative Pressure (Competitiveness) and Mimetic Pressure (Client demand). The external drivers include Increase Finance and Performance, Increased productivity, and Innovation.

In this study, it has been revealed that some of the identified key drivers have a high importance in fuelling the implementation of industry 4.0 strategies in the UK infrastructure sector. Organisations' competitiveness has been identified as one of the main drivers as there is high competition within the sector in terms of work winning. In addition, the introduction of government standards BS-1192 (now ISO 19650) and PAS-1192 has pushed organisations within the sector to attempt to adopt digital and automated processes to adhere to standards, however, this adoption and implementation is highly dependent on their understanding of these new processes and the organisations' ability to fully understand the key drivers as they play a key role in their decision-making. This is vital as organisations need to understand the impact their choice of industry 4.0 strategy will have where the level of implementation is highly dependent on the organisations' experience and whether they possess the internal resources to make this possible.

The Total Interpretive Structural Model was used to assess and outline the relationship between the key drivers identified. Competitiveness was identified to be the top level of the TISM while Client Demand, Increased Finance and Performance, and Increased Productivity were found to be at the bottom end of the model. Higher management within the organisations and the decision makers should consider the drivers at the bottom end of the hierarchy as they can gain a deeper understanding of these drivers to enable a successful implementation of the chosen Industry 4.0 strategies. To further the analysis of this research, the results from the TISM were imputed in the Fuzzy MICMAC analysis to identify the dependence and driving powers of the generated industry 4.0 drivers. Government laws have been identified as the most influential key drivers which have the most influence on industry 4.0 strategies being implemented successfully within the UK infrastructure sector.

4.3.KEY INDUSTRY 4.0 INITIATIVE IMPLEMENTED IN THE UK INFRASTRUCTURE SECTOR

It has been noted that there are six main Industry 4.0 agendas which have been adopted within the UK infrastructure sector based on the thematic analysis. The six main technologies are (1) BIM, (2) 3D models, (3) Big Data, (4) Drones, (5) GIS and (6) Point clouds and Digital Surveys. Each Industry 4.0 technology has been explained more in-depth separately in Chapter 6 and supported by the relevant literature.

Table 0.2: Key Industry 4.0 agenda implemented within the UK infrastructure sector.

	Industry 4.0 strategy adopted	**Uses for Industry 4.0 Strategy**
Economical	3D models	- Visualisation - Collaboration - Risk identifying - Identifying clashes - Buildability - On-site Space visualisation

Social	Big Data	- Data integrity - Data review - Sharing of data - Having a CDE - Analysis of volumes - Quantity analysis - Quantification
Environmental	BIM	- Collaboration - Construction planning - Visualisation - 4D sequencing - 5D cost planning - CO2 calculation - Data management on models
	GIS	- Data visualisation - Realspace visualisation with assets - Planning
	Drones	- Visualisation - Progress monitoring - Environment monitoring
	Point Clouds and Digital Survey	- Existing condition visualisation - Surrounding planning - Modelling (using pre-existing data) - 4D modelling of existing conditions of the environment

The manufacturing industry is now going through the fourth industrial revolution, however, the infrastructure sector compared to other businesses is behind in adopting these automated and digital processes. this study has identified six key Industry 4.0 technologies that organisations within the infrastructure sector have implemented most on their projects. The implementation levels of these Industry 4.0 technologies differ across all the larger organisations, however, the small to medium-sized organisations seems consistent. The industry 4.0 agenda Building Information Model (BIM) implementation is High to medium for large organisations within the infrastructure sector, however for small to medium-sized organisations the level is extremely low. 3D models are another industry 4.0 agenda identified, this sits at a high level for large organisations and very low for small and medium size organisations, with the BIM mandate this is expected as the implementation of BIM and UK Government standards require 3D models. The third technology identified is Big Data, the level of implementation for Big Data is medium-to-high for large organisations and low for small to medium size organisations, one of the large organisations that took part however achieved a low to medium level in terms of implementation of the top three technologies identified, this is due to no digital strategy established at the time of interview. The fourth technology GIS also received a level of medium to high for larger organisations whereas small to medium-sized organisations received a low level. The final two technologies Drones and Point clouds and digital surveys receive a medium to high level while small to medium sized organisations are at a low level for drones but low to medium level for point cloud and digital survey implementation.

4.4.KEY CHANGE MANAGEMENT STRATEGIES IMPLEMENTED BY THE UK INFRASTRUCTURE SECTOR

Three key aspects were focussed on which were highlighted as the main change management strategies adopted affecting Industry 4.0 agenda. The key change management practices are presented in Table 4.3 and are explained in more detail in this chapter. The three main aspects which have been noted are (1) People, (2) Tools/technologies, and (3) Strategy.

Table 0.3: Summary of key change management strategies implemented in the infrastructure sector to manage industry 4.0 agenda.

People	Training for employees
	Knowledge sharing between competent staff
	Raising awareness
Tools/Technologies	Integrating new technologies
	Pushing projects to become data focussed

	Integration between organisations' projects
Strategies	Digital Transformation
	New organisational structure
Processes	Change in Work Environments
	Change in processes

The transformation to the fourth industrial revolution has pushed organisations and businesses to implement changes to numerous properties of their organisation to accommodate the changes. A change in people and staff within the organisation from all levels can accelerate the vision of innovation throughout the business as everyone within the organisation having the same goals increases interest throughout the organisation. Furthermore, new competencies will be introduced with Industry 4.0 agenda which will allow changes in the roles and responsibilities of staff. However, people and staff are only one factor as despite training and increasing competency and capabilities of staff, without the tools and technologies available Industry 4.0 agenda is impossible to adopt and implement. Despite the clear necessity for tools and technologies to be available, organisations tend to have challenges to gain buy-in from senior members of the organisation, this is why some organisations have developed digital and innovation strategies set from a high level allowing senior members of staff to gain understanding of the new processes and how to implement the changes. Knowledge and understanding have been key challenge factors affecting the adoption of Industry 4.0 agenda as identified within this research and literature, increasing understanding of Industry 4.0 agenda implications and procedures is vital enabling the entire organisation and supply chain to understand and expand their knowledge. This promotes innovations and demonstrates how a return on investment can be obtained through adopting the new procedures.

4.5.MAIN CHALLENGES FACED IN IMPLEMENTING INDUSTRY 4.0 AGENDA

The challenges faced within the UK infrastructure sector concerning Industry 4.0 agenda adoption and implementation have been identified using thematic analysis. Six main challenges have been identified and presented: (1) Software and hardware, (2) Knowledge and understanding, (3) Organisation Culture, (4) Resistance to change, (5) Competency and Capabilities, and (6) Funding and Investment barriers. There are additional sub-challenges which have been categorised into the main challenges identified demonstrated in Table 4.4. Each challenge is expanded on separately in Chapter 8.

Table 0.4: Industry 4.0 agenda adoption challenges and their subthemes

Software and Hardware	- Interoperability - Cost of software and licence
Knowledge and understanding	- Lack of Knowledge and clarity - Lack of understanding of new processes involved with industry 4.0 agenda across the organisation. - Lack of awareness relating to Industry 4.0 - Lack of guidelines and standards
Organisation Culture	- Lack of support from senior staff - Lack of engagement throughout the organisation - Lack of clarity on goals and outcomes on adoption within organisations
Resistance to Change	- Individually within staff - Group level within teams - Organisational level
Competency and Capabilities	- Lack of competent staff for new processes - Lack of human resources
Funding and Investment	- High initial cost - Lack of funding for resources - Long-term financial gain

This study presents an effort to quantify the challenges identified using a systematic approach and the Graph Theory and Matrix approach. The UK infrastructure sector currently has major barriers that are creating a blockage for the implementation of Industry 4.0 agenda. One of the challenges identified is "Software and Hardware" which has been found to have the most impact in terms of a challenge for organisations within the sector. Due to the costs of software and hardware at the initial stages of industry 4.0 agenda implementation, organisations tend to not have a return-on-investment vision as despite the high cost of software and hardware businesses can gain and benefit from gaining profit in future in addition to this, on top of costs for the software and hardware, most software require licences which come at an additional cost. Due to implementation and adoption processes taking some time, organisations fail to envision the future benefits. "Organisation Culture" was found to be the second most impactful challenge affecting the infrastructure sector. This challenge is important because without the change in organisational culture to enter a digital and innovative mindset and organisation's vision, industry 4.0 agenda implementation, the new processes have a very slim chance to be utilised where they can be beneficial to the organisations. This is due to a lack of common organisation vision as a group as individuals within the organisation may employ a more innovative way of working, however, this is not filtered throughout the organisation.

The third most impactful challenge is "Funding and Investment", due to the uncertainty of return on investment, organisations tend to resist providing investment for these new processes. In addition, small and medium-sized organisations do not have the costs of implementation due to their average turnover, for small and medium-sized businesses, the investment is not worth the turnover as they do physically not have the cost of implementation. "Resistance to Change" is the fourth most influential challenge identified which has been found to originate from individuals within the organisation's reluctance to adopt new digital and automated processes, this is caused by individuals' perception culturally on Industry 4.0 agenda. The fifth and sixth most influential challenge to organisations in the UK infrastructure sector both score the same while quantifying the challenges, these challenges are "Knowledge and Understanding" and "Competency and Capabilities". These two challenges have the same ranking in terms of most influential challenge as they both relate to each other, with more knowledge and understanding within the staff, they can become more competent and gain more capabilities for these new processes.

4.6.INDUSTRY 4.0'S CONTRIBUTION TO UK INFRASTRUCTURE SECTOR

There have been several contributions highlighted within the UK infrastructure sector due to the implementation of Industry 4.0 agenda, these have been generated through thematic analysis using the triple bottom line approach. There have been three main contributions identified: (1) Economic Values, (2) Social Values, and (3) Environmental Values, which are presented in Table 4.5. These contributions are further investigated in separate within this section.

Table 0.5: Industry 4.0 agenda implementation impact using TBL.

Economic Values	Innovative business models
	Increased competitiveness
	Increased productivity
Social Values	Increased connectivity
	Improved stakeholder relationship
	Social Innovation
Environmental Values	Reduction of CO2 emissions
	Reduced Energy Consumption
	Reduce waste

The interviewees have expressed multiples of values gained through implementing Industry 4.0 agenda which is in line with the three dimensions presented by the TBL. The social aspects which have been adopted by organisations in the sector produced key values in improving social integration among stakeholders, the improvement the connectivity and communication through IoT improves stakeholder relationships. Environmental values include the reduction of emissions, this is through data and automation which can allow the sector to achieve net zero emissions as per the UK Government's Net Zero Strategy, reduced waste and reduction of energy consumption are other values that have been identified through implementing Industry 4.0 agenda. Economic performance has also been improved through becoming more productive, organisations being more productive increases their competitiveness within the sector leading to more work winning and financial profits while reducing operational costs. Additionally, innovative business models can improve reputation within the sector. The Organisations within the infrastructure sector have acknowledged that they must meet clients' and stakeholders' requirements and vision. Therefore, organisations within the sector should guarantee that they have the resources and capabilities to adhere to stakeholders' and clients' requirements and needs, this is why the implementation of Industry 4.0 agenda within the sector can be considered a profitable occasion, as long as organisations performance is considered high economically, socially and environmentally, they can gain financial returns and perform well.

CHAPTER 5: ANALYSIS OF KEY DRIVERS FUELLING THE NEED FOR INDUSTRY 4.0 STRATEGIES IN THE UK INFRASTRUCTURE SCETOR

5.1.INTRODUCTION

In this chapter, the key drivers that have fuelled the implementation and adoption of Industry 4.0 strategies will be focused on. This chapter provides answers to the Second and Third research questions:

"What are the key drivers that have fuelled the need for embracing Industry 4.0 agenda in your organisation? "

And

"What is the relationship between the key drivers?"

The results have been derived from qualitative data collected from 21 interviews with experts in the sector from 13 different organisations. the findings presented are based on the participants' opinions supported by the relevant literature reviewed.

In this chapter, the results are divided into three main sections which are as follows:

- Thematic analysis: This analysis was undertaken to identify the key drivers that are encouraging organisations for the implementation and adoption of Industry 4.0 agenda.
- TISM analysis: This method of analysis was conducted to emphasize the relationships between the drivers identified.
- Fuzzy MICMAC analysis: This analysis was chosen to analyse and outline the driving powers of the key drivers identified.

Six key drivers identified were analysed with the use of RBV and institutional theory, and the relationships identified between the drivers were studied further with the use of TISM and Fuzzy MICMAC analysis. The chapter finally concludes by highlighting recommendations and implications from the results.

5.2.COERCIVE PRESSURES: GOVERNMENT ENFORCES LAWS

Latif et al (2020) define the term coercive drivers to be driving forces impacted and driven by powerful forces such as governments, based on the literature gathered and reviewed, it has been found that government push has been one of the biggest drivers of the adoption and implementation of Industry 4.0 agenda such as the Building Information Model (BIM) within the UK infrastructure sector. A few of the interviewees from this research study have highlighted Government push as one of the key drivers within their organisations for the adoption and implementation of Industry 4.0 agenda. Interviewee PARE8 stated about the government mandate on specific technology included in Industry 4.0 agenda, the interviewee uncovers that the UK government has a huge impact in driving Industry 4.0 agenda within the infrastructure sector. Mandates and standards such as ISO16950 (2019) have played a major part in transforming the infrastructure sector to becoming digital. Ratnasingam et al (2019) (Ratnasingam, et al., 2019), Gopalakrishnan et al (2012) (Gopalakrishnan, et al., 2012) and Eadie et al (2006) (Eadie, et al., 2007), are one of many types of research that have emphasised the importance that standards mandated by the government have on businesses and organisations. government forces are considered one of the most influential drivers as it leaves minimum choices for organisations than to adhere to regulations set.

A good example of government laws and standards changing the infrastructure sector is the mandate of BIM with standards BS-1192 and PAS-1192 being introduced. The mandate of Level 2 BIM minimum was introduced in 2016 and saw all public sector projects in the UK the contract is over 12 months and worth £10,000,000 or more are "forced" to adopt and implement BIM on their projects (Infrastructure and Projects Authority, 2016). The standards have recently, in the year 2019 been updated to ISO 19650. Interviewee PARE6 provided insight as to how Industry 4.0 agenda used on one of their government-funded projects was mainly focussed on client satisfaction due to the mandate of BIM providing government pressure, interviewee PARE6 has asserted that the government have introduced pressure within the infrastructure sector to become digital and automated and in terms of BIM, the setup of a framework for the organisations to have available as a guide ensures that these digital strategies are implemented. Despite there being rules to adopt and implement technologies such as BIM, this may lead to organisations being forced to increase their costs to accommodate the changes necessary to meet government requirements. In addition to increased costs, adopting new ways of working can also lead to disruption within the organisation. These challenges are explained further in Chapter 8.

The 2016 BIM mandate has forced organisations to adopt Industry 4.0 agenda to achieve goals of improved efficiency and costs savings which can be possible from the start during the pre-construction stages of a project, this has benefitted the sector where risks are eliminated from before construction, in addition, early digital involvement in projects with the standards set by the government followed has indicated the increase in competitiveness or organisations. Interviewee PARE2 cites:

> *"The UK government has a massive push for this having lots of strategies which have come from aiming to reduce over budget and delayed time on projects. Essentially, we need to work smarter and improve our profit margin."*

As interviewee PARE2 stated, the adoption of digitised and automated processes encourages their organisation to work smarter and improve their profit margin, this inspires the organisations to adopt Industry 4.0 agenda. Despite the challenges and changes organisations face in implementing Industry 4.0 agenda, organisations are forced to implement digital means which are now usually added to their contract during the tender stages of projects.

Regardless of the UK government's mandate, organisations in the infrastructure sector are still struggling to implement level 2 BIM fully. Organisations that are dedicated to becoming digital have been making the effort to fully comply with the standards set by the government however some of the interviewees have highlighted that they have not implemented BIM in the project they are on. Ratnasingam et al (2019), argue that even with the government's push to adopt Industry 4.0 agenda, organisations may not be ready to adopt and implement Industry 4.0 agenda as incentives or tangible economic benefits may need to be provided to organisations. Nedelko (2021) has identified that organisations need to identify and differentiate between their organisational drivers and personal drivers for Industry 4.0 agenda (Nedelko, 2021).

In summary, the UK government has introduced coercive pressure which is shown by the standards set for public sector projects adopting and implementing a minimum of Level 2 BIM to drive the digitisation and automation of the infrastructure sector. This pressure has pushed organisations within the industry to improve their processes with the use of digital aids in addition to improving their organisations' competitiveness. Even though industry 4.0 agenda such as BIM is mandated in the UK, some organisations are still yet to follow government standards and implement and adopt BIM level 2 as a minimum on their projects, therefore it can be argued that the coercive pressure from the UK government may not be fully recognised as the biggest and sole driver to adopt and implement industry 4.0 agenda, in addition, the government mandate only accommodates for public sector projects over where the contract is over 12 months and worth £10,000,000 or more, which leads to small and medium-sized organisations are exempt for the mandate. It is suggested that during the creation of the standards of the mandate, organisations within the sector of different sizes being included in this process and clearly outlined strategy would encourage organisations to implement Industry 4.0 agenda efficiently.

5.3.NORMATIVE PRESSURES: COMPETITIVENESS

Within the infrastructure sector, competition has increased over the years as there are many organisations submitting bids for projects to win the work. In the literature, Bienhaus and Haddud (2018) indicated the biggest push generating motivation and drivers for the adoption of Industry 4.0 strategies is competitiveness, they stated:

> *"An increasing competition, also deriving from new market entries, forces organisations to increase their potential of innovation to maintain Digitisation of procurement and supply chains competitiveness within the newly created business models and concepts"* (Bienhaus and Haddud, 2018).

To analyse the above statement from Bienhaus and Haddud (2018), competition pressures drive organisations to become more innovative as during this fourth industrial revolution, the digital process adopted by organisations takes a major role in work winning.

Participants in this research have considered the pressures applied by competing organisations within the sector which is one of the main drivers in the implementation of Industry 4.0 agenda, Interviewee PARE7 cites:

> *"[...] the key drivers for future for us would be competition and winning work due to loss of work to other contractors."*

The interviewees' declaration suggests that there is a lot of competition in the infrastructure sector which is pushing organisations to become more innovative and adopt Industry 4.0 agenda. Ratnasingam et al (2019), have argued that industry competitiveness is affecting smaller firms and organisations as the larger organisations could fund and implement Industry 4.0 agenda more efficiently. Due to large organisations adopting Industry 4.0 agenda, the organisations that are behind in this innovation are pushed to raise their competitive advantage and win work from their competitors hence this driven them to adopt and implement Industry 4.0 agenda. Tvaronaviciene and Burinskas (2020) have noted competition within an organisation is to be moved from *classical competition* to *qualitative new competition* which should be based on the following factors (Tvaronaviciene and Burinskas, 2020):

- Innovation: This provides the capability to deliver products at a faster pace.
- Customer-friendly designs: Using a variety of designs digitally can enable flexible options to be explored with the best practice adopted as a result.
- Risk reduction: Exploring automated processes, especially during the initial stages of a project allows the best process to be chosen which eliminates risks that are faced in the industry.

In addition to organisations' competition, Antunes et al (2018) highlight Industry 4.0 agenda providing competitive advantages at an international level rather than focusing on the organisation level (Antunes, et al., 2018). Infrastructure is a big part of economic growth and innovation within the construction and operations of infrastructure can boost the economy of the UK massively allowing the UK to be ranked highly within the international economy. Interviewee PARE1 explained how the adoption of Industry 4.0 agenda within their organisation is mainly focussed on providing a higher competitive advantage to their organisation by achieving better asset maintenance and operation once the project is completed:

> *"In our project, we have a visualisation hub which we are producing to get all our CAD and digital information where it would be the digital representation of our physical asset. To us, it helps the organisation achieve what we want to achieve in future."*

Organisation competition is a big factor within the infrastructure sector as it could affect the number of projects, they win essentially meaning that without being competitive, their organisation could be in danger. Despite this, not all organisations have the funding and resources available to adopt Industry 4.0 agenda hence it can be argued that competition is a key driver however this does not mean that all organisations within the infrastructure sector see competitiveness as a good enough driver to fund innovative processes.

5.4.MIMETIC PRESSURE: CLIENT DEMAND

The client is the biggest stakeholder within the infrastructure sector as they play a massive role in the success or failure of an organisation. clients can choose which organisation to assign projects to which is where the organisations gain their profit. Cunha et al (2020) stress the importance of meeting clients' unique demands as each client would have their innovative requirements which also results in the creation of value for the organisations (Cunha, et al., 2020). Mergeline and Lemus-Aguilar (2021) highlight the need for a "smart client" where this can be defined as the concept of the client introducing and mandating innovative and smart processes as a must with their contractors and appointed parties (González-Santander and Lemus-Aguilar, 2021). In this study, some of the interviewees have stated that the main key driver in their organisations' adoption of industry 4.0 agenda is client demand, however, they have noted that within the infrastructure sector, there are sub-contractors who are classed as small to medium-sized organisations that are hired by the appointed contractors, this client demand can be unreasonable as the small to medium size organisation may not have the required resources or funding to enable industry 4.0 agenda. Despite client demand being a key driver for some of the interviewees, interviewee PARE8 revealed that within their organisation, most clients are not demanding the implementation and adoption of Industry 4.0 agenda.

> *"I think the people looking at it within my organisation are usually fuelled through innovation funding to show their capabilities, so I think it is mainly for building a reputation of innovation and work winning but not many clients are asking for it."*

To expand on Interviewee PARE8's statement, organisations within the infrastructure sector do have drivers such as innovation funds being in place for innovative processes, however, within their organisation not many of their clients are requesting innovative processes to be implemented on their projects resulting in traditional practices being used instead as the budget of costs for the project may not accommodate for the resources and other aspects which will be necessary to adopt and implement industry 4.0 agenda. In addition to this, many small and medium organisations also take up work on these projects, these small and medium size organisations have a small revenue from these projects compared to the larger organisation, and the small and medium size organisation also would struggle with resources and competency of their staff which may cost them more for implementation than larger organisations within the sector. Interviewee PARE3 states:

> *"The idea for our organisation is to improve efficiency and increase client satisfaction, this would benefit us in different ways we can show the clients that we are good at what we do and can implement new processes to reduce risks of going over budget and time"*.

The results show that some clients not demanding industry 4.0 agenda, most clients in the UK infrastructure sector are aware of the importance of innovation where during the tender stages of the project and assigning a contractor, the clients are looking out for innovative practices within contracts to ensure that processes are being adopted to eliminate projects going over budget and time. For organisations this means that they generate a higher chance of being awarded the contract, however, not only do the innovative processes have to be in writing but also must be practised within the project to gain full client satisfaction, demonstrating to the clients that they are capable and can result in further contracts being won in future projects as this enhances the organisations' reputation.

5.5.INTERNAL PRESSURES

5.5.1. INCREASED FINANCE AND PERFORMANCE

Organisations within the UK infrastructure sector gain their profit from completing projects on time, or before programmed time leading to costs cut as resources will not have to be paid for, for a longer duration as the project would have been completed before the anticipated project end date. This can benefit organisations and in addition, show current and future clients that the organisation performs productively and efficiently. Delays are the biggest profit loss factor within the infrastructure and delays can be caused especially due to lack of productivity and non-efficient practices.

Zizek et al (2020) express the importance of key performance indicators within Industry 4.0 agenda. The performance of an organisation in terms of Industry 4.0 illustrates the key input that is required in the form of data for an organisation in becoming digital (Žižek, et al., 2020). Despite the performance being a key driver, in terms of Industry 4.0, Zizek et al (2020) highlight that for Industry 4.0 agenda, there is a lot of literature available, however, there is a major challenge in measuring the performance of Industry 4.0 agenda. Regardless of the performance of Industry 4.0 agenda being a challenge to indicate, the interviewees have expressed that their organisations are motivated to implement Industry 4.0 agenda as it would increase the performance of their organisation resulting in increased finances. For instance, Interviewee PARE9 highlighted digital pressures on their organisation to become smarter:

> *"[...] Essentially, we need to work smarter and improve our profit margin. My organisation has implemented DFMA and innovation investments."*

The analysis of the above statement reveals that organisations view Industry 4.0 as a process in which they can gain profit by using digital and automated processes. As part of the motivations for industry 4.0 agenda adoption, organisations see this innovative adoption to accelerate smart working within their organisation and projects and improve profit. Ching (2019), Shufutinsky et al (2020), Menon et al (2020), and others have emphasized increased profit as one of the main motivators for organisations in implementing new innovative technologies. Ching (2020) cites:

"To improve productivity, and when productivity improves with Industry 4.0, the average cost decreases which, in turn, will then contribute to increasing profit margin." (Ching, 2019)

Ching expresses how organisations adopting and implementing Industry 4.0 agenda are aiming to improve their productivity with new innovative processes which can be more efficient than traditional practices, despite having to be up-front costs at the start of adoption and implementation, organisations will benefit from a return in an investment where the traditional processes are more costly than the new innovative processes as aspects such as staff resource can be cut due to automated and digital processes.

In summary, the pressure exerted by the industry motivates organisations to become more productive and improve their performance and profit margin. For this reason, Industry 4.0 agenda is on the radar of organisations within the infrastructure sector as the use of digital and automated processes can enable organisations to perform better within their field and increase profit for the entire organisation. However, it should be noted that despite profit margins being potentially raised through the adoption and implementation of Industry 4.0, there can be high up-front costs which mean that organisations with the budget to invest in Industry 4.0 applications will be able to provide costs for that, however small and medium sized organisations would see it difficult to place that upfront costs as they possess the ability to provide the upfront cost for adoption and implementation.

5.5.2. INCREASED PRODUCTIVITY

Besides the common of increased finance and performance, the interviewees have also expressed the importance of efficiency and productivity within the infrastructure construction sector, where having digital solutions can enhance this productivity and efficiency during all stages of the assets lifecycle. Organisations can achieve a lot with the reputation they have, which can lead to winning contracts and jobs. Being an innovative organisation and having solutions where innovative ideas can provide better productivity and enable cutting costs and time during the project construction. Nedelko (2021) identifies lean production as one of the organisational drivers which encourage Industry 4.0 implementation and adoption (Nedelko, 2021).

Hopkins (2021) has identified the key drivers of adopting Industry 4.0 strategies in Australia for the manufacturing industry as a means for cost improvement, better quality, and delivery (Hopkins, 2021). The views that have been identified in current research correlate with the views which have been observed within the literature of this study. The interviewees have also expressed increased productivity and how Industry 4.0 strategies can benefit infrastructure assets during construction and in the future. For illustration, interviewee PARE4 stated:

> *"I think we would like to be more productive as a business with the available technology. Becoming more productive means for us we can have faster processes resulting in cost saving for both us and the stakeholders."*

To analyse the statement from Interviewee PARE4, productivity is a key aspect within any business as the more productive the business is the more possibility of profit gain. In the infrastructure sector, as mentioned previously, projects can tend to become over time and budget, becoming more productive within the sector with innovative practices can result in organisations completing projects on time or even better early and within budget. This benefit can allow the organisations to gain a higher profit margin, in addition to this, the organisation's reputation will be highly improved and can lead to more work being won for the organisation. Like PARE4, Cavalcantea et al (2019), Dubey et al (2019), and Frank et al (2019), have all noted the impact that Industry 4.0 agenda has on the productivity of organisations (I.M. Cavalcantea, 2019); (R. Dubey, 2019); (A.G. Frank, 2019). To analyse statements from Cavalcantea, Dubey and Frank, it has been noted that Industry 4.0 agenda can promote virtualisation and automation throughout the traditional production process. This is because rather than completing tasks within the infrastructure construction process in a manual and time-consuming manner, automated practices can result in tasks being conducted in minutes with technology rather than hours or days. Furthermore, organisations can cut costs on resources, Industry 4.0 technologies may need a high amount of human interaction at the start for data inputting and set up to become automated, however once set up, these technologies will require minimum human interaction meaning that organisations can cut costs on resources that would normally undertake the tasks.

To summarise, organisations in the infrastructure sector can gain a lot from being more productive as a business, therefore implementing more productive processes is a key driver for industry 4.0 agenda adoption. Therefore, productivity should act as a driver for managers and senior members of the organisation's attitude towards the adoption and implementation of Industry 4.0 agenda.

5.5.3. INNOVATION

Taylor (2017) highlights the multiple definitions that can be used to define the term "Innovation". Different fields such as the government, academia, and industry each define innovation differently with different interpretations and understanding of the term. Taylor (2017) defined Innovation as:

> *"The creative process whereby new or improved ideas are successfully developed and applied to produce outcomes that are practical and of value"* (Taylor, 2017)

Silva et al (2020) asserted the importance of innovation within the construction sector with Industry 4.0 agenda (Silva, et al., 2020). Silva et al express the importance of innovative technologies and how Industry 4.0 agenda can transform the sector through automation, however, it has been noted that there was a lack of publications on digitalisation within the construction sector, similarly, digitisation and automation within the infrastructure sector. Innovation is still a goal of organisations within the infrastructure sector despite there being minimum implementation, Interviewee PARE5 cites that their organisation has been motivated to adopt Industry 4.0 agenda to become more innovative:

> *"I think everything is innovative now, so we have a lot of innovative ideas being trailed and tested to meet up with requirements."*

To analyse Interviewee PARE5's statement, it reveals that there are a lot of innovative ideas within the organisation within the infrastructure sector which is leading to the trial and testing of these different innovative ideas. The idea for these innovative ideas is to assist in meeting requirements set by clients and stakeholders. During an infrastructure project, different clients may ask for different standards and requirements from contractor organisations, due to this, different projects undertaken by the same organisation may have different automation and digitisation requirements which can lead to some projects being less digital than others despite some other projects undertaken by the same organisation may have adopted multiple industry 4.0 technologies. In line with Muller et al (2018), have argued that the innovation of a business is key for leading change as new and better processes will be introduced allowing clients to have confidence within the organisation chosen for their projects (Müller, et al., 2018).

Innovation within a business shows the growth of an organisation and requires them to invest in the capabilities and resources that are required for the successful adoption and implementation of new processes. Organisations that acquire innovations show clients and stakeholders that they contain more productive and efficient processes as most of their processes can be automated resulting in a project that is not over time and budget.

To summarise innovation is a key driver for organisations within the infrastructure sector adopting and implementing Industry 4.0 agenda. Organisations within the infrastructure sector understand the value of innovation in terms of client and stakeholder satisfaction, clients gain confidence in productive and efficient processes which is what Industry 4.0 agenda can provide for an organisation. Therefore, organisations should aim to adopt and implement Industry 4.0 agenda to ensure their organisation processes are innovative to aid the increase of their work winning and profit margin.

5.6.TOTAL INTERPRETIVE STRUCTURAL MODELLING (TISM)

In this study, total interpretive structural modelling was utilized to identify the interrelationship between the drivers that have fuelled organisations in the infrastructure sector to implement Industry 4.0 agenda. The steps detailed in "Chapter 3" were applied and the TISM allowed themes to be identified by organisations that took part in this study as to what have been their key drivers for adopting and implementing Industry 4.0 agenda. With the provided information from the participants of this study, TISM was undertaken to illustrate the relationships between the drivers that have been identified. In addition to this, the relationships between the drivers will also allow a more in-depth understanding of the current state of Industry 4.0 agenda within the infrastructure sector. The main stages of undertaking TISM are listed below:

- Six key drivers were identified from the participants' results.
- Relationships between the key drivers identified are established.
- The responses from the interviewees captured were used to interpret the contextual relationships.
- Development of an interpretive logic-knowledge base is developed to aid within the pair-wise comparison for the identified six drivers.
- A reachability matrix is then created and examined for transitivity.
- The produced final reachability matrix is then split into different stages.
- A digraph is then created centred around the results of the stages split with the direct links and the necessary transitive links taken into consideration.
- An interpretive matrix is then created with the interactions of the digraph.

- The TISM model is then established and examined for any potential inconsistencies and any modifications necessary were conducted.

Table 0.1: Key drivers and their assigned numbers

No.	Key driver
1.	Government Laws
2.	Competitiveness
3.	Client Demand
4.	Increased Finance and Performance
5.	Increased Productivity
6.	Innovation

5.6.1. IDENTIFICATION OF THE CONTEXTUAL RELATIONSHIP

A contextual relationship was defined to identify the causal relationship between the key drivers identified, the relationship was defined by determining does "key Driver impact or influence Key Driver 2".

5.6.2. INTERPRETIVE RELATIONSHIP

The experts' results aided the interpretation and contextual relationship formation to identify whether "Key Driver 1 has an impact of influences Key Driver 2". If the case is that there is an impact or influence on other drivers, this can be explained by detailing "How does Key Driver 1 influence or impact Key Driver 2".

5.6.3. INTERPRETIVE LOGIC OF THE PAIR COMPARISON

For the pair-wise comparison of the identified six Key Drivers, an interpretive logic of pair comparison was undertaken. An example is shown in Table.5.2:

Table 0.2: Example of interpretive logic-knowledge pairs regarding Competitiveness

No.	**Key Driver No.**	**Paired comparison of Key Drivers**	**Y/N**	**What impact/influence does one KD have on the other KD?**
1	KD2-KD3	Competitiveness Impacts/Influences Client Demand	Y	Organisations' competitiveness can be an influential by client demand based on clients' requirements

2	KD2-KD4	Competitiveness Impacts/Influences Increased Finance and Performance	N	-
3	KD2-KD5	Competitiveness Impacts/Influences Increased Productivity	N	-
4	KD2-KD6	Competitiveness Impacts/Influence Innovation	Y	Increasing the competitiveness of an organisation through innovation can influence and impact work winning.

5.6.4. REACHABILITY MATRIX AND TRANSITIVENESS

An initial reachability matrix was developed, demonstrated in Table 5.3 to understand the interpretive logic-knowledge by using the code “1” for a “Y” code and a “0” for a “N” code in the interpretive logic-knowledge pair comparison. The matrix created was then assessed for its transitiveness resulting in the initial matrix being created which can be seen in Table 5.4. In the case that the transitivity links between the key drivers reach 50% or above based on the opinions of the experts taking part in this study, then the link is deemed as a significant link between Key drivers which needs interpretation.

Table 0.3: Initial Reachability Matrix

No	Key Drivers	KD1	KD2	KD3	KD4	KD5	KD6
1	Government Laws	1	1	1	0	0	0
2	Competitiveness	1	1	1	0	0	1
3	Client Demand	1	1	1	0	0	0
4	Increased Finance and Performance	0	0	0	1	0	0
5	Increased Productivity	0	0	0	0	1	1
6	Innovation	0	1	1	0	1	1

Table 0.4: Final Reachability Matrix

No	Key Drivers	KD1	KD2	KD3	KD4	KD5	KD6	Power of Drive
1	Government Laws	1	1	1	0	0	0	**3**
2	Competitiveness	1	1	1	0	0	1	**4**
3	Client Demand	1	1	1	0	0	0	**3**
4	Increased Finance and Performance	0	0	0	1	0	0	**1**
5	Increased Productivity	0	0	0	0	1	1	**2**
6	Innovation	0	1	1	0	1	1	**4**
	Dependency power	**3**	**4**	**4**	**1**	**2**	**3**	**17/17**

5.6.5. LEVEL ASSIGNING

A level partition was conducted to determine the levels of each Key Driver, this is illustrated in Table 5.5.

Table 0.5: Level Assigning for Key Drivers Identified.

Key Driver No	Reachability Set	Predecessor Set	Intersection	Assigned Level
Iteration 1				
1	1,2,3	1,2,6	1,2	
2	1,2,3,6	3,4,5,6	3,6	
3	1,2,3	1,3,6	3	I
4	4	4,5	4	I
5	5,6	1,2,4,6	6	I
6	2,3,5,6	1,3,5	3,5	
Iteration 2				
1	1,2	1,2,6	2	II
2	3,6	3,4,5,6	3,6	

6	3,5	1,3,5	5	II
Iteration 3				
2	3,6	3,4,5,6	3,6	III

5.6.6. DEVELOPMENT OF DIGRAPH

The Key Drivers that were identified are determined in a digraph with the defined levels taken into consideration as it will aid in providing the direct links to the transitivity links. The digraph is demonstrated in Figure 5.1.

5.6.7. INTERPRETIVE MATRIX

An interpretive matrix was established which is illustrated in Table 5.6.

5.6.8. TOTAL INTERPRETIVE STRUCTURAL MODEL (TISM)

Using the information provided by the interpretive matrix and the digraph, the total interpretive structural model was developed demonstrated in Figure 5.2.

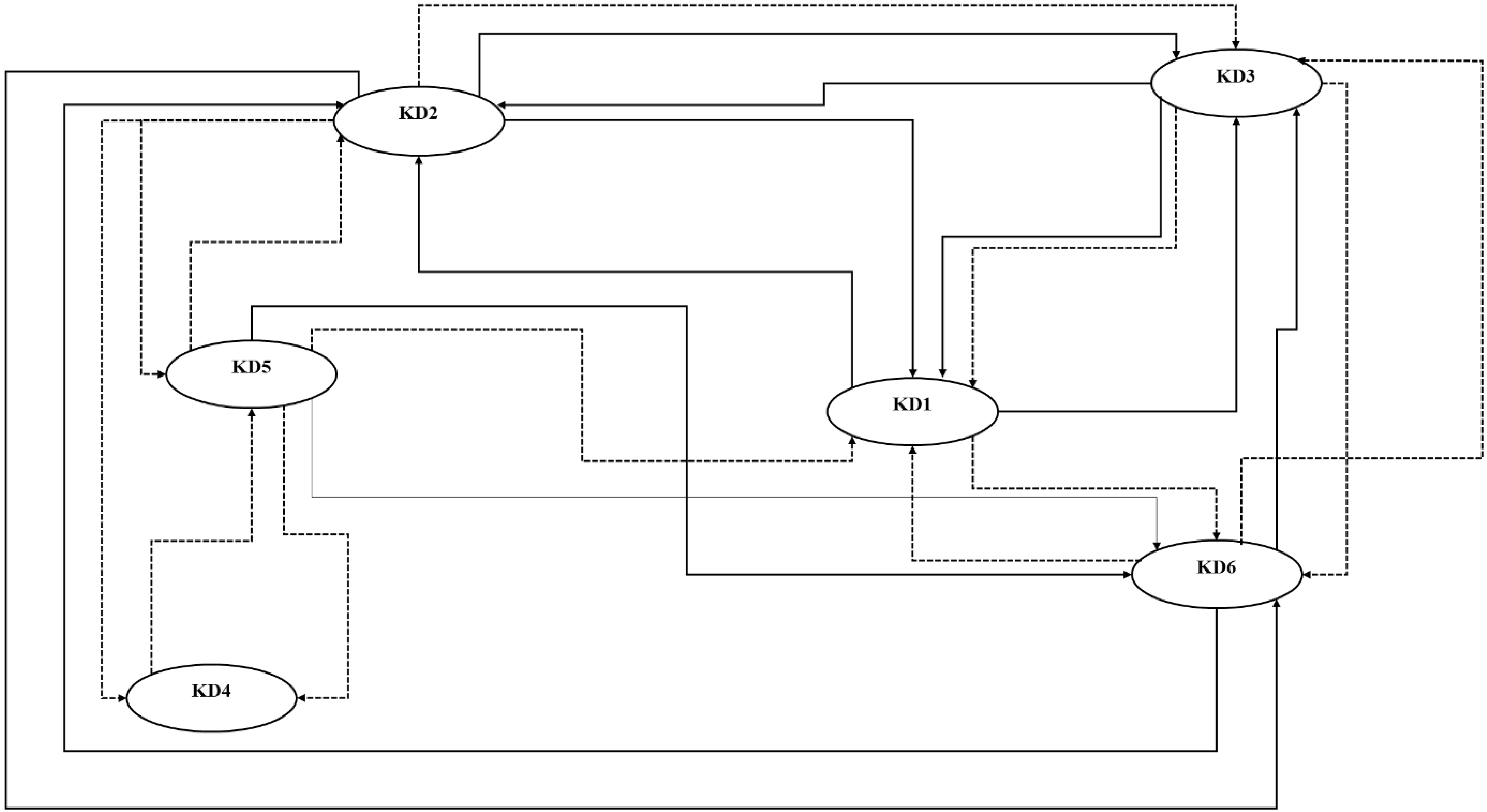


Figure 0.1: Diagraph

Table 0.6: Interpretive matrix

KD No.	KD1	KD2	KD3	KD4	KD5	KD6
KD1	-	Government push on organisations boosts the competitiveness of organisations adopting digital standards	Push from the government will lead to clients demanding Industry 4.0 agenda as part of the scope	-	-	Encourages organisations to become more innovative
KD2	-	-	An organisation's competitiveness can be an influential by client demand based on clients' requirements	Better processes can boost the competitiveness of an organisation.	Increased Productivity increases organisations competitiveness	Increasing the competitiveness of an organisation through innovation can influence and impact work winning.
KD3	-	Client demanding industry 4.0 agenda allows organisations to increase productivity with technology benefits as clients demand them.	-	-	Clients demanding Industry 4.0 agenda leads to increased productivity for organisations	Clients tend to demand innovative practices from organisations-appointed contracts which influence organisations.
KD4	-	Increased performance of an organisation is reflected in their competitiveness	-	-	Increased finance and performance allow organisations to be more productive	-
KD5	-	An increase in an organisation's productivity benefits its competitiveness in the sector.	-	An increase in performance can increase productivity	-	Innovative processes influence productivity based on processes adopted
KD6	Innovation is part of digital government standards	-	-	-	-	-

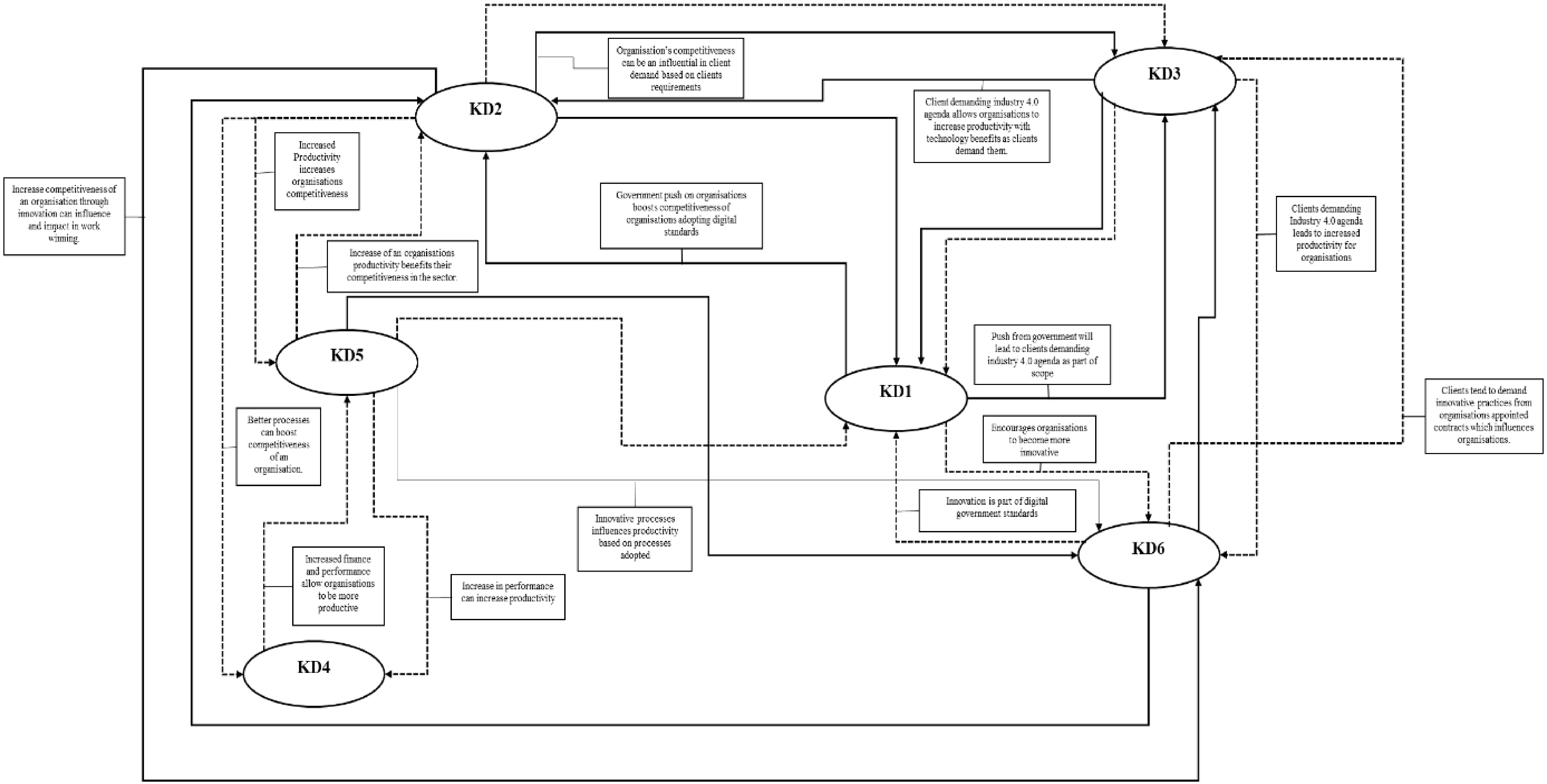


Figure 0.2: Total Interpretive Structural Model (TISM)

5.7.Fuzzy MICMAC

The produced reachability matrix presented in Table 5.4 clearly shows that the key driver *Competitiveness* (KD2) has an impact on *Increaser Productivity* (KD5), *Increaser Finance and Performance* (KD4), and *Innovation* (KD6), these have all been assigned a similar impact value of 1. However, the influence value assigned cannot be the same between different drivers as this does not demonstrate which driver is more influential. Thus, the fuzzy theory is applied to introduce different assigned levels of influence and relationships between the drivers to obtain better analysis results. The fuzzy MICMAC step applied has been described in Chapter 3.

Creation of the BDRM (Binary Direct Relationship Matrix)

Table 5.7 portrays the BDRM that has been developed.

Table 0.7: Demonstration of Binary Direct Relationship Matrix

No	Key Drivers	KD1	KD2	KD3	KD4	KD5	KD6
1	Government Laws	0	1	1	0	0	0
2	Competitiveness	1	0	1	0	0	1
3	Client Demand	1	1	0	0	0	0
4	Increased Finance and Performance	0	0	0	0	1	0
5	Increased Productivity	0	0	0	0	0	1
6	Innovation	0	1	1	0	1	0

Production of the LADRM (Linguistic Assessment Direct Reachability Matrix)

The proposed linguistic scale is demonstrated in Table 5.8 which presents alternatives described by the fuzzy MICMAC to allow the analysis of the key drivers and their dependence power. Within the TISM, the only values utilised to denote the relation between two key drivers were 0 and 1. These values have been selected as a level of impact as there can be uncertainty in human language to further analyse the impact each key driver possesses.

Table 0.8: Fuzzy Linguistic Scale

Linguistic scale	Fuzzy value
Very High Influence (VH)	(0.75, 1.0, 1.0)
High Influence (H)	(0.5, 0.75, 1.0)
Medium Influence (M)	(0.25, 0.5, 0.75)
Low Influence (L)	(0, 0.25, 0.5)
Very Low Influence (VL)	(0, 0, 0.25)
No Influence (No)	(0, 0, 0)

The values of the key drivers' relationships have been assigned with the aid of the experts within the industry, these are presented in Table 5.9.

Table 0.9: Linguistic Assessment Direct Reachability Matrix

No	Key Drivers	KD1	KD2	KD3	KD4	KD5	KD6
1	Government Laws	0	M	L	0	0	0
2	Competitiveness	L	0	M	0	0	VH
3	Client Demand	VH	M	0	0	0	0
4	Increased Finance and Performance	0	0	0	0	M	0
5	Increased Productivity	0	0	0	0	0	H
6	Innovation	0	VH	M	0	VH	0

Defuzzification

The defuzzification method has been used as the presentation of the LADRM does not fall in line with available matrix operations. This has allowed the LADRM to be converted into numbers as demonstrated in Table 5.10.

Table 0.10: Fuzzy direct reachability matrix

No	Key Drivers	KD1	KD2	KD3	KD4	KD5	KD6
1	Government Laws	0	0.5	0.25	0	0	0
2	Competitiveness	0.25	0	0.5	0	0	1.0
3	Client Demand	1.0	0.5	0	0	0	0
4	Increased Finance and Performance	0	0	0	0	0.5	0
5	Increased Productivity	0	0	0	0	0	0.75
6	Innovation	0	1.0	0.5	0	1.0	0

Table 0.11: Stabilised Fuzzy MICMAC matrix.

No	Key Drivers	KD1	KD2	KD3	KD4	KD5	KD6	Driving Power
1	Government Laws	0.25	0.75	0.5	0	0.75	0.75	3.0
2	Competitiveness	0.25	0.5	0.5	0	0.75	1.0	3.0
3	Client Demand	1.0	0.5	0	0	0.25	0.25	2.0
4	Increased Finance and Performance	0	0	0	0	0.5	0	0.5
5	Increased Productivity	0.25	0.5	0	0	0.25	0.75	1.75
6	Innovation	0.25	1.0	0.5	0	1.0	1.0	3.75
	Dependence Power	2.0	3.25	1.5	0	3.5	3.75	14/14

5.8.DISCUSSION

This study has highlighted six key drivers for the implementation of Industry 4.0 agenda within the UK infrastructure sector from the interviewee responses. The drivers were then analysed to identify their relationship using Total Interpretive Structural Modelling (TISM). A TISM was established which is presented in Figure 5.2 where the findings have suggested that Client Demand, Increased Finance and Performance, and Increased Productivity represent Level I.

Government Laws and Innovation represent Level II and the final driver at the third level (Level III) is Competitiveness.

With the use of the TISM, it has been found that "Competitiveness" is a vital driver within the UK infrastructure sector for implementing Industry 4.0 agenda. Any changes in this key driver will have an impact on the other key drivers identified. Currently, there are no Government laws on Industry 4.0 agenda apart from BIM, hence the organisations within the infrastructure sector view improving their competitiveness as a vital driver as it increases their work winning hence improving financial performance and productivity within organisations. It has been found that Client Demand, Increased Finance and Performance, and Increased Productivity have the least impact on the organisations' implementation of Industry 4.0 agenda as their input is mainly dependent on the other identified drivers. Government laws for example directly impact client demand for implementation of Industry 4.0 agenda, this encourages clients to ask for the Industry 4.0 initiatives to be a part of organisations' contracts to meet government standards and laws.

The Fuzzy MICMAC analysis has been adopted to carry out the analysis of the dependence and driving powers of the key drivers identified within the UK infrastructure sector, this has allowed the validation of the TISM model that was developed. The key drivers have been categorized into four clusters which have been defined by Singh et al (2018):

- Cluster 1: Autonomous
- Cluster 2: Dependent
- Cluster 3: Linkage
- Cluster 4: Independent (Singh, et al., 2018)

In the first cluster, the autonomous drivers comprise the key drivers with weak driving and dependency powers. The second cluster demonstrates the dependent drivers which have a weak driving power but strong dependency power. The third cluster contains the linkage drivers which have both driving and dependency powers which are strong, and the final cluster demonstrates the independent drivers which have a strong driving power but low dependency power.

Autonomous drivers

Two key drivers identified in this study fall under the autonomous driver's cluster namely Client demand and Increased Finance and Performance. Both key drivers contain weak dependence and driving powers meaning they appear to be separated from the system. They are linked to the other drivers however the linkage is considered weak. Consequently, these two key drivers are not considered to have a substantial influence when it comes to industry 4.0 strategies implementation. Therefore, higher-level management within the infrastructure sector should not consider these key drivers as a priority for a successful Industry 4.0 strategy implementation.

Dependent drivers

Increased productivity falls under the dependent drivers within the system. This is characterised by having a weak driving power but strong dependence power. This demonstrates that this key driver is very much dependent on the other drivers to guarantee its influence on the organisations within the sector when implementing industry 4.0 strategies. The high dependence power suggests that the driver cannot encourage the implementation of Industry 4.0 strategies on its own. This key driver requires other key drivers to already be driven for it to have an impact effectively. For example, if organisations implement industry 4.0 strategies this enables productivity to be increased. Dependent powers are important for higher management within the organisations within the sector to envision what can be focused on once industry 4.0 strategies are at the start of implementation, this allows the understanding of the drivers which can benefit an efficient implementation.

Linkage drivers

Within the third cluster, the key drivers that fall in this are Innovation and Competitiveness. The linkage drivers are known to be unpredictable as a change in one of the key drivers will in turn impact the remaining drivers within the model. The key drivers in this cluster can influence drivers that are at the same level which can impact Industry 4.0 strategies implementation within the UK infrastructure sector, it is unclear if these key drivers will impact the implementation of Industry 4.0 strategies either positively or negatively. These dependents are heavily dependent on the other key drivers such as most of the external drivers such as Government laws. Thus, higher management within organisations in the UK infrastructure sector should pay attention to these sorts of drivers as they influence the system based on feedback.

Independent drivers

Key drivers with a strong driving power and weak dependence power are illustrated in the fourth and final cluster, Government laws fall under this cluster as it contains a high driving power and can be classed as the most important key driver for the implementation of Industry 4.0 strategies within the UK infrastructure sector. This is because the key driver is the main source of encouraging organisations within the sector to implement industry 4.0 strategies to a high extent within their projects. This key driver should be handled by higher management with care as it is important in the success of implementing industry 4.0 strategies, in addition, it is of high strategic importance within organisations in terms of industry 4.0 within the sector.

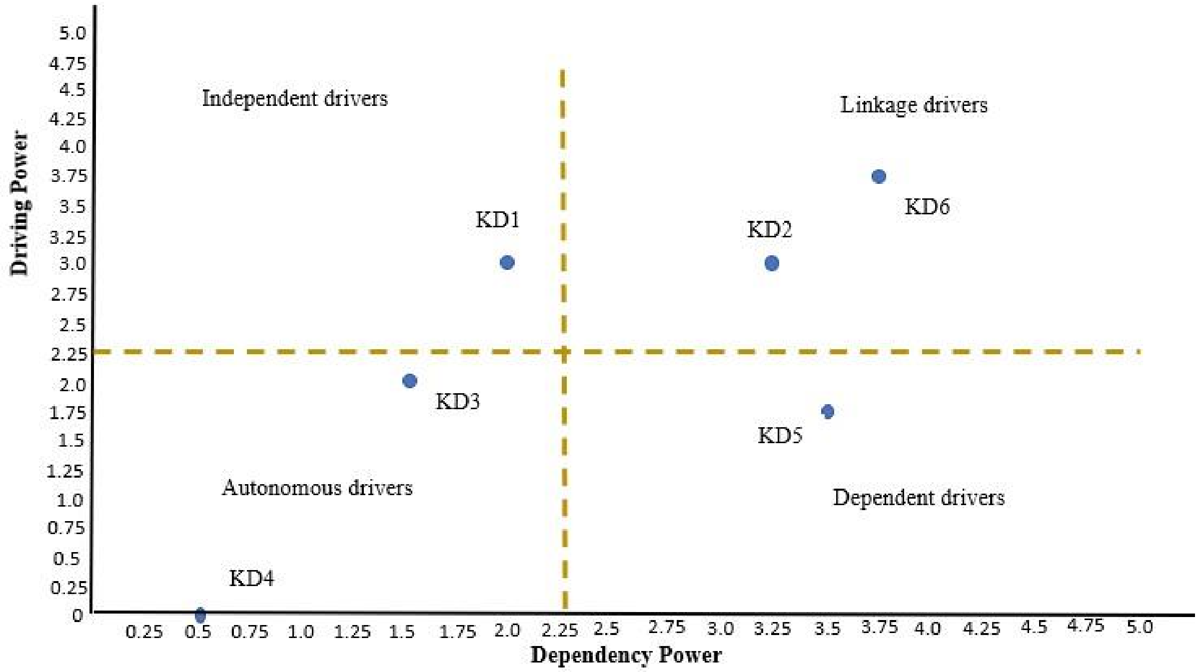


Figure 0.3: Fuzzy MICMAC representation

5.9.SUMMARY

Overall, below are the identified implications which have been documented:

Theoretical implications

This chapter demonstrated a new insight into industry 4.0 strategies from the UK infrastructure perspective. This has not been done before, in addition, the key drivers that fuel the UK infrastructure sector to implement industry 4.0 strategies are explored which has not been available in the current literature. Adopting a multi-theoretical approach has allowed the key drivers identified which have been ignored in the available literature and have not been conducted before for the UK infrastructure sector.

Managerial implications

In this chapter, the practical implications of the organisations within the UK infrastructure sector have been explored in the implementation of Industry 4.0 strategies. This allows higher management to gain an understanding of the drivers and how they would impact their organisation in successfully implementing industry 4.0 strategies. Additionally, this chapter established the relationships between the identified drivers that influence the implementation of Industry 4.0 agenda. This supports higher management within the sector to visualise the relationships enabling a deeper understanding of the key drivers that are highly influential, thus higher management should work with the government as organisations are to follow the external drivers and would need to fully understand the drivers to recognise what internal capabilities are required for successful implementation.

Below are the recommendations that are presented for the sector, government, and organisations to act upon and assess.

- Government and organisation collaboration: The UK Government should include the UK infrastructure sector when creating Industry 4.0-related laws and regulations to allow the progress of general and valuable policies.
- Policy: The Government should generate a straightforward framework to increase the UK infrastructure sectors leading power, this will allow them to generate a compensation force towards the UK infrastructure sector.
- Outreach projects: The UK infrastructure sector should create a network where local communities and organisations within the sector can gain trust and understanding.
- Stakeholder relationships: Organisations within the UK infrastructure sector should involve stakeholders within the decision-making process, these include employees, members of the community, suppliers, and representatives of customers, this could create a major impact in Industry 4.0 strategies adoption.

CHAPTER 6: ANALYSIS OF THE KEY “INDUSTRY 4.0 STRATEGIES” THAT ARE CURRENTLY IMPLEMENTED IN UK INFRASTRUCTURE SECTOR ORGANISATIONS

6.1. INTRODUCTION

In this chapter, the analysis of the key Industry 4.0 agenda implemented within the UK infrastructure sector are discussed. These answers the presented fourth and fifth research questions:

“What are the key ‘Industry 4.0 strategies’ that are currently being adopted within the infrastructure sector?”

And

"What is the current level of implementation of Industry 4.0 strategies within the infrastructure sector?"

The findings presented in this chapter are based on the qualitative data analysis which was collected from 21 experts within 5 different large organisations and 8 medium/small organisations in the infrastructure sector. The literature review conducted was also considered in addition to experts' opinions. Table 6.1 highlights the key industry 4.0 strategies that have been implemented within the organisations that have taken part in this study and their uses for these strategies.

Table 0.1: Key Industry 4.0 agenda implemented within the UK infrastructure sector.

	Industry 4.0 strategy adopted
Economical	3D models
Social	Big Data
Environmental	BIM
	GIS
	Drones
	Point Clouds and Digital Survey

In this chapter, the results are split into two main sections which are the Thematic analysis being used to identify the key industry 4.0 agenda which have been adopted in the UK infrastructure sector; and the maturity model which assesses the level of adoption and implementation across the organisations that took part in the study from the participants results. The maturity model was chosen to assess and represent the level of the organisations' implementation of Industry 4.0 agenda. The final section of this chapter will summarise the results and provide recommendations.

6.2.KEY INDUSTRY 4.0 STRATEGIES IMPLEMENTED

6.2.1. BIM

The UK government mandated the Building Information Model minimum level 2 for all public sector projects in the UK over the contract is over 12 months and worth £10,000,000 or more. Due to this, most large-scale infrastructure public sector projects have BIM standards implemented as most if not all their projects will cost over £10,000,000. Jallow et al (2019) demonstrate many cases within the UK infrastructure sector projects that have implemented and adopted BIM at the time of the study (Jallow, et al., 2019). This mandate by the UK government has forced organisations within the sector to adopt and implement BIM on their projects, however, due to the mandate only accounting for public sector projects over £10,000,000, many small and medium-sized organisations do not have BIM adopted within their organisation which can result in projects not fully implementing BIM as these small/medium size organisations may work with the larger organisations despite not having the BIM capabilities.

Gledson and Greenwood (2017) explain the impact of Innovative practices and the adoption of these processes are decisions made by making a strategic decision within the organisations rather than individual members of an organisation's decision. Gledson and Greenwood then went on to describe the adoption of 4D BIM in organisations that took part in their study, 4D BIM was adopted by a high number of organisations at the time of their study, however despite being adopted, 5.2% of those participants who adopted 4D BIM emphasise that 4D BIM is not compatible with their current implemented work practices and processes which will cause more disruption than benefits adopting a new process (Gledson and Greenwood, 2017). Alreshidi et al (2017) support the importance of innovation and explain the UK government mandate of BIM by the construction sector in 2016 (Alreshidi, et al., 2017), Alreshidi et al stress the barriers that are faced in the adoption and implementation of BIM one of them being technological barriers which will be expanded on in Chapter 8 demonstrating the challenges of Industry 4.0 agenda adoption and implementation. In this study, the participants have noted that their projects have adopted BIM level 2 as per the mandate set by the UK government, from the interviewee's responses, 3D models are of big use within the infrastructure sector. One of the participants PARE4 noted that:

> *"We have BIM as a huge part of our project, we have 4D strategy and 5D strategy".*

From the participants' statement, some organisations within the infrastructure sector are aiming to go beyond just 3D models and data, some organisations have adopted 4D and 5D strategies on their projects. This adoption of 4D and 5D means that the 3D models contain a lot more data in the form of time and cost to provide 4D sequences and 5D cost calculations. Cheng et al (2017) explain the benefits that 4D and 5D can provide as different scenarios can be tested before implementation to evaluate risks, health and safety, space proofing, cost, and time for the project (Cheng, et al., 2017). Cheng et al focus on the decommissioning stage of construction using 4D and 5D BIM, they have highlighted decommissioning options for an offshore oil and gas platform, and they have expressed that 4D and 5D BIM enables construction operations to be visualised and monitored which is vital for this process. The 4D and 5D BIM enabled space proofing to be analysed for decommissioning and safety can also be analysed, despite its potential, the use of 4D and 5D BIM for decommissioning has very little study or practice. Interviewee PARE1 noted:

> *"We have had a great promotion of the project due to the implementation of BIM, especially 4D and 5D which we used during scheme design which has increased client satisfaction and cost savings through saving CO_2 emissions and finding better ways of building."*

The interviewee's statement goes in line with Cheng et al's (2017) idea that 4D and 5D simulation can benefit the construction industry. The interviewee expresses how 4D and 5D BIM have been implemented in their organisation, in addition to this they have benefitted from CO_2 emissions cut through 5D + where they have integrated a 5D+ tool which calculates the carbon footprint of the project allowing different material or building options to be tested to determine the best practice to cut CO_2 emissions during their project. Despite the mandate and adoption of BIM across organisations, there is still a massive amount of upskilling to be undertaken, as Interviewee PARE5 highlights:

"I started on this project a few months ago but there is a push for people to get BIM certified encouraging more awareness by training our staff members."

The interviewees' statement revealed that despite BIM being one of the major industry 4.0 technologies adopted and implemented widely within the sector, organisations are still providing upskilling and training opportunities for their staff as BIM as a process can only have a successful implementation and adoption if it is widely adopted across all members of the organisation. This goes in line with Linbald and Guerrero (2020) as they have highlighted the importance of the competence of organisations for BIM adoption and implementation.
Lindblad and Guerrero explain that organisations can benefit from creating "BIM Networks" where experience and knowledge can be shared improving competence within the organisation (Lindblad and Guerrero, 2020).

Despite the BIM mandate by the UK government, there are still large organisations that fit the criteria to follow the mandate but have not implemented or adopted BIM within their projects. Several interviewees have highlighted that despite their role being in the digital team of their organisations, the project they are working on does not have BIM of any levels adopted or implemented. Interviewee PARE8 cites when asked what Industry 4.0 agenda was implemented within their organisation:

"There is none, no technologies at all have been implemented so far. I think when and if clients from a higher level ask for this then my organisation would be more proactive in adopting these technologies. Or if we had other companies showing these technologies, this may fuel my organisation to adopt some of these technologies."

In line with the interviewees' statement, Masood and Sanntag (2020) also highlight that SMEs are aware of Industry 4.0 strategies and technologies, however, not many SMEs have adopted Industry 4.0 strategies as suggested from the results gathered in this research study (Masood and Sonntag, 2020). Interviewee PARE7 also noted when presented with the interview question, simply:

"There is none."

The interviewee expressed that within the project they are working on as a Head of Digital and Technical assurance there is no Industry 4.0 agenda adopted or implemented BIM being one of the technologies not adopted despite being a large organisation and the UK government mandate.

Organisations within the infrastructure sector have a responsibility to adopt and implement BIM as part of the government mandate, current organisations that have adopted and implemented BIM are good examples within the business and the more reason why the sector should collaborate and engage as lessons learnt and how challenges have been overcome can be shared throughout the business this is mainly because some organisations are extremely far ahead in terms of BIM adoption implementing 4D and 5D BIM on their projects where other organisation, despite being large scale, are yet to adopt any form of BIM standards on their projects. For instance, Organisation D which is a large organisation in the UK consisting of different sectors is behind in terms of BIM adoption and implementation. BIM has been adopted and implemented as per the UK government's mandate; however, this is solely on other sectors within the business not including their infrastructure sector. unlike Organisation A, Organisation B, Organisation C, Organisation E and Organisation F, this organisation is having challenges that they currently have not overcome for the adoption and implementation of Industry 4.0 agenda, in addition to this as mentioned an additional eight small and medium size organisations took part in this study, these organisations have expressed due to their size, adoption and implementation of BIM is not undertaken. For these small and medium-sized organisations, most of their contracts are not over £10,000,000 as the UK government suggested implementing level 2 BIM as a minimum for projects over £10,000,000. However, these small and medium size organisations tend to take on work with larger organisations whose projects will be over £10,000,000 and would have BIM implemented, this results in BIM processes not being followed throughout a project's organisation as the small and medium size organisations employed as subcontractors by the larger organisation would have very low BIM capabilities.

6.2.2. 3D MODELS

Within the UK infrastructure sector, 3D models are widely implemented mainly because 3D models are a part of BIM standards which have been mandated. 3D models benefit the sector as visualisation virtually is made possible which is a benefit that can lead to saving costs and time while increasing productivity and eliminating risks for any construction project. Cheng et al (2017) express the importance of 3D models as 3D models allow the objects to be assigned to tasks in the programme of works enabling 4D virtualisation to be possible. in addition to this, the 3D models allow 5D costs and 5D+ carbon calculations to be possible as we have noted from the participants' responses that one of the organisations that took part in this study mentioned that they have undertaken CO2 emission calculation with the use of 5D+. Interviewee PARE5 cites:

“We work with 3D models, however now with the current project I’m working for we have 3D models with more information in terms of Data.”

To explain Interviewee PARE5's response, in line with the UK Government's mandate, 3D models are being adopted within the UK infrastructure sector following the BIM standards mandated. Sharif et al (2017) explain how 3D models can be manipulated to provide a variety of viewpoints and assessment within construction (Sharif, et al., 2017). Sharif et al (2017) express how automation with the use of 3D models can enable monitoring of construction to become a lot more efficient as a process with automated tools. not only is progress monitoring a benefit, but also assessing different scenarios and quality control for example Interviewee PARE15 noted:

"We have found that using the Building Information Model during the early stages of lockdown helped in coordinating virtually while we were not allowed to be on-site due to lockdown rules and restrictions which has helped us maintain productivity."

To explain Interviewee PARE15‘s statement, they found using the 3D model available as part of the Building Information Model implemented on their job has helped immensely. A task was set on site however this was delayed due to Covid-19 by three weeks as the task involved a beam of a viaduct being demolished, though this was not proving possible as something was blocking the beam into the viaduct. With the aid of the 3D model, the beam could be visualised as the survey manager was not able to go on-site and survey the beam due to the lockdown rules. The interviewee has stated how much more efficient this process was compared to having staff on-site at a high health and safety risk on an MPD platform to survey the beam. Daniotti et al (2020) explain how within construction, the availability of a 3D model with the virtual assets can allow the extraction of necessary documentation throughout the stages of construction, this adds value as the different members of the organisations and project team can access real-time data with the most up to date information, reducing the risk of constructing on data and construction information that has been updated (Daniotti, et al., 2020). Interviewee PARE3 cites:

“On the project I am working on we have implemented BIM which we have integrated both the data and 3D models with other technologies to get an integrated approach using it for planning out our works before construction.”

The interviewee's statement revealed that organisations are aware of the benefits of 3D models during the pre-construction stage and are implementing their use for various processes. this goes in line with Daniotti et al (2020)'s argument that 3D models allow virtualisation and automation throughout the stages of construction.

6.2.3. BIG DATA

Big Data is a topic that has gained a lot of attention over the past couple of years. Big Data has been developed due to large amounts of data which are required to be managed. many industries have been using Big Data as businesses such as banking and healthcare work involve masses of data which can be near impossible to manage (Reyes-Veras, et al., 2022). With the Building Information Model mandate in the UK, the standards involve gathering information throughout the assets lifecycle from the pre-construction stage to Operation and maintenance, different systems may also be involved which is why organisations within the infrastructure sector have adopted and implemented Big Data to assist in information management within this complex process. Motawa (2017) explains that within the construction industry, massive volumes of data are required to be managed whether it is structured or unstructured. The data is all created through the construction process which is why Big Data can create major benefits to the industry despite organisations adopting Big Data, the industry is still behind on Big Data adoption, however, Motawa's (2017), study shows that Big Data is a technology which is known within the industry but limited adoption within the industry (Motawa, 2017). In line with Motawa (2017), Interviewee PARE4 states:

> *"So, we are trying to apply automation within our projects with the use of data from the supply chain. We are looking to check data automatically instead of the tasks being manual due to the nature of our projects consisting of many third parties and interfaces. We are also working on big data and storage of the information we currently use the cloud, and cyber security for the information being stored, there are many aspects our organisations are working on and building on to implement in the future. We are more focused on big data within our organisation."*

To explain Interviewee PARE4's statement, the participant explains how their organisation is focused on Big Data adoption. Within the infrastructure sector, most projects involve many different third parties and interfaces, this means that data is to be shared between them and these third parties and interfaces also have information and data which may be required for the project, such as utilities lines underground. Due to the masses amounts of data within their projects, automation was adopted, and Big Data allowed the projects to store project information securely and efficiently. Organisations are focused on Big Data within the infrastructure sector as the collated and stored data can act as a single source of truth within the whole organisation, Lui et al (2021) explains more on the use of big data within Tunnel construction with the use of TBM's. Lui et al (2021) expand on how lithology affects the tunnelling process and tends to delay projects. Tunnelling can be heavily affected by the geology of the location, geology contains a lot of uncertainty despite geology analysis and geology surveys as these methods of assessing the underground and drill and blast to bore the tunnels, however, despite the working process, extra drilling may be required and the TBM may be required to be suspended which leads to a delay in works. Lui et al (2021) describe how the use of Big Data can assist the TBM excavation as existing information can be utilised in predicting lithology a lot more accurately ensuring an efficient TBM tunnelling process (Lui, et al., 2021). Interviewee PARE6 highlights the main industry 4.0 technology as Big Data within their organisation:

> *"We have machine control as I have said, however, we haven't got a lot, the only real technology I would say is the Internet of Things as we are looking to have a single database instead of a variety of them so having a common data environment."*

To expand on interviewee PARE6's statement, their organisation has adopted the Internet of Things and databases to store Big Data for the operation and maintenance of the project. As part of BIM Level 2 standards in the UK, organisations are required to have a Common Data Environment (CDE) which essentially is the centre of all project information meaning that there is a single source of truth, in addition to this, 3D models are required to contain a set of data for each element depending on the standards and client requirements. The UK government's BIM mandate has pushed most organisations to adopt and implement big data as it is part of the adoption of BIM level 2 scope creating a demand for the technology. The implementation of Big Data has allowed organisations to review and share data efficiently, in addition to this quantity analysis also becomes a more automated process, for instance, Interviewee PARE9 cites:

> *"We have been using Big Data, which is big within our organisation currently, on the projects I am working on we have a lot of earthworks, we created a Power BI dashboard to summarise volumes for us which is not only useful for the site team but the commercial team in calculating costs or labour, how many days we would need to hire excavators and so on."*

To explain Interviewee PARE9's statement, Big Data can assist in summary calculations, especially for large projects where calculating the amount of material required to be excavated

or the amount of material to fill can be time-consuming and involve many risks in the estimation of quantity. In line with the PARE9's statement, Maeda and Fujiwara (2016) highlight the importance of using Big data in construction mining, Maeda and Fujiwara describe how Big Data can be utilised in mining to calculate scenarios such as earthquakes, ground motion, quantity and material of the ground (Maeda and Fujiwara, 2016). Reyes-Vera et al (2021) argue that despite the benefits of Big Data, businesses find it difficult to define the term, Big Data, in addition, some of the data can be incompatible with characteristics of
Big Data, which can create more work and more costs at the start of implementation to ensure competent staff and proper implementation of the new process is successful (Reyes-Veras, et al., 2021), it is clear that Big Data has been implemented amongst the organisations of the participants that took part in this study, however, Big Data technology adoption creates new working processes which need to be defined and organisation need to ensure that competent staff are available and training and upskilling should be held for a successful implementation of Big Data.

6.2.4. DRONES

Drones are currently widely known and used across many businesses and currently, the Construction infrastructure sector is adopting drones' technology within their projects. drones have many uses such as photogrammetry for 3D and aerial surveys just to name a few. Li and Liu (2019) express the importance of land surveying within construction, especially in land development as there are many moving parts whether it be in the form of excavation, filling of land or transferring of soil (Li and Liu, 2019). Within the construction infrastructure sector health and safety is a key factor as workers are exposed to the possibility of fatalities and severe injuries, the construction industry initially saw drone technology as a potential to improve safety measures of projects. In line with Li and Lui, Yi and Sutrisna (2021) also express the risks of safety in construction, as within the industry there is a possibility of fatalities, in addition, especially for linear infrastructure projects monitoring of project progress can be difficult as the project can tend to be miles long and for projects with a lot of earthworks, the monitoring of works carried out daily may go un-noticed as it may not be grand enough to be obvious when viewing in real life (Yi and Sutrisna, 2021). Yi and Surisna (2021) have expressed that drone technology can be utilised to monitor areas of work on construction projects more efficiently while reducing health and safety risks as staff and workers would not be required to travel to the construction site to undertake this monitoring. Interviewee PARE2 has expressed the use of drone technology within their organisations and especially on the project they are working on, Interviewee PARE2 states:

> *"Drones for our sector have been amazing for seeing progress within our sector as its linear, compared to buildings which may not be that useful to have drones."*

The analysis of Interviewee PARE2’s statement uncovers that within the infrastructure sector in the UK, organisations are aware of drone technology. Drone technology in the industry, specifically in the project Interviewee PARE2 is currently on has been useful in terms of creating point clouds. the survey team within the project are using drone technology to create point clouds every week monitoring the progress of work. As the drone surveys are being conducted weekly, these can be overlayed where the progress from the previous week or previous weeks can be compared to the current state of work. The interviewee expresses that as the projects they are working on is a linear project, the monitoring of work tends to be a lot easier with the drones surveys provided by the survey team, especially during Covid-19 most staff working from home cannot view the work progressing on site, the availability of these drone point cloud surveys allowed staff members that have not been on site due to the pandemic to understand the working being carried out despite working from home full-time. Zaychenko et al (2018) argue that drone technology implementation within the construction industry provides a variety of benefits and uses, however, drone technology just like most technology does have its disadvantages. for instance, Zaychenko et al (2018) found that some challenges to be faced with drone technology implementation include projects knowing exactly what the purpose of the drone data is, collecting the right data and upskilling staff to pilot the drone technology adoption and implementation (Zaychenko, et al., 2018). Drones within the industry are being used for more than construction purposes, the largest rail project in Europe currently utilises industry 4.0 technologies, PARE2 noted that during their Tunnel Boring Machine (TBM) launch, drones were used for stakeholder engagement where the nation witnessed the TBM launch live. Despite this, PARE2 noted that there is only one drone available on the project where the industry 4.0 technology is being used for stakeholder engagement and visualisation of site progress, the drones on the project are not being used to their full potential due to a lack of competent staff on the project, this topic is explored further in Chapter 8, where challenges are discussed. It is recommended that staff within organisations be upskilled to be more competent and understand the value of industry 4.0 technologies, adding value to the organisations themselves.

6.2.5. GIS

Geographical data systems are very common within the sectors of the construction industry. Location and logistics are a big part of the construction which is where GIS implementation assists massively within the industry. GIS has been predominantly 2D in previous years, however with the BIM mandate leading to most organisations already having access to 3D models as it is part of BIM Level 2 standards, BIM and GIS can be integrated where the proposed design 3D models can be integrated with GIS allowing proposed/designs to be viewed with current information and visualization (Basir, et al., 2020). Floros et al (2020) however argue that despite BIM and GIS integration being a beneficial outcome, there are interoperability issues to this day (Floros, et al., 2020). Despite challenges, Floros et al (2020) have expressed that BIM and GIS can work collaboratively presented by the initiative known as "GeoBIM Benchmark 2019" (Noardo, et al., 2019), this demonstrates the capabilities of the two tools and software as both are dominant standards within the industry. A few of the participants that took part in this research have cited the implementation and adoption of GIS within projects they are working on, for instance, Interviewee PARE6 noted:

> *"The only systems that have benefited from it are GIS and power BI within my organisation. We have had drones to monitor progress and we have fully implemented BIM and looking at Virtual Zone training."*

To explain Interviewee PARE6's statement, on the project that they are working on, GIS has been the main Industry 4.0 agenda implemented which has been beneficial towards the project. the project uses FME and Power BI which are beneficial for projects in terms of Data location extraction and specifically Power BI for data management. Similarly, for most of the participants that have taken part in this study, Interviewee PARE6 expresses that both BIM and GIS have been implemented in their project, this goes in line with Floros et al (2020) who have highlighted that BIM and GIS are the two main standards implemented within projects in the industry. Floros et al (2020) also describe the BIM and GIS integration, which was highlighted by one of the participants, Interviewee PARE3 cites:

> *"We have incorporated our BIM 3D models into our GIS JV maps which we call 3D GIS, it provides the site team visualisation of our assets in real-time integrating our design models with existing maps and surveys."*

To expand on Interviewee PARE3's statement, the project has integrated BIM and GIS, which is like Floros et al (2020) idea of bringing the two main standards together.

Interviewee PARE3 ‘s project has achieved a BIM and GIS integration where the 3D design models are combined with existing logistics and information. This provides a GeoBIM environment for the project which has been very useful for the site team in terms of looking at the right data and information at the right time, Basir et al (2018) also discuss BIM and GIS integration which seems to be a trend within the construction industry (Basir, et al., 2018). Industry Foundation Classes (IFC) was developed to minimise connectivity and interoperability issues within the construction industry, this IFC was implemented in Interviewee PARE3’s project as the project utilises Bentley Aecosim as the modelling software, and the software and models generated from it are only available on Bentley software and systems which tends to be difficult for third parties and interfaces to open and access as they may not have the necessary tools and software licence to visualise designs and gain project data. Due to this, the participant has expressed that within their project, to avoid interoperability issues, once the design models are provided to the organisations' BIM team from the designers, checks are undertaken to ensure that the model meets the standards and requirements highlighted in the EIR (Employees Information Requirements) and BEP (BIM Execution Plan), the models are then exported to different file types such as IFC, Dwg, and 3D pdf which allows the GIS team to incorporate IFC files within their GIS system leading to 3D GIS. In addition, the different file types also allow interfaces and third parties who do not have Bentley licences which can tend to be very costly can be provided with the option of different file types to view design data and models.

With the BIM mandate within the industry, GIS has also become a common theme and organisations are attempting to manage a BIM and GIS integration, however, despite its known potential benefits, the integration between BIM and GIS can prove to be difficult due to interoperability and connectivity of the two processes. The initiative for BIM and GIS integration can tend to lead the industry to become more efficient in terms of work planning and automation changing the organisations' capabilities for the better.

6.2.6. POINT CLOUDS AND DIGITAL SURVEY

Surveys are a normal process within the infrastructure sector as when constructing assets, a survey of the existing land is necessary for organisations to be aware of aspects such as utilities, ground level, and ground conditions which is why the infrastructure sector has been increasing the use of point cloud and survey data as some projects in the industry have witnessed an increase in productivity, quality and safety through the adoption and implementation of these industry 4.0 agenda (Mirzaei, et al., 2022). The UK infrastructure sector takes into consideration many factors during their projects with Health and Safety being one of the key priorities for the industry, therefore organisations across the infrastructure sector and construction sector have adopted Digital surveys and point clouds. For instance, Interviewee PARE2 states:

> *"Point clouds we have implemented in our surveying team, I would not say the use of it is consistent, however, it is implemented in some way."*

To analyse Interviewee PARE2's statement, it is evident that point clouds and digital surveys are implemented within the infrastructure sector, however despite the technology being available it is not consistent as staff members within the organisation and project do not seem interested in utilising the benefits provided by the technology. The point clouds and digital surveys allow the site team to digitally recreate real-life objects on a real-life scale which can be visualised by all teams of the organisation, Hori and Ogawa (2017) support this theory in their research, they have outlined the new dimension introduced with point could surveys within archaeology (Hori and Ogawa, 2017). Hora and Ogawa (2017) describe how the use of point cloud survey data can benefit the archaeology processes as point cloud survey allows them to visualise the data and create their final report saving time travelling on-site and rising health and safety risks.

Tang et al (2010) argue that laser scanners can be used to capture information throughout the lifecycle of the asset. As Hora and Ogawa (2017) have stated, point cloud information and survey data can be collected to create archaeology reports where these may be required at the start of a project, Tang et al (2010) express the use of laser scans and point cloud survey can be used during post-construction at the asset's operation and maintenance stage. While surveys are of great use within projects while construction, during the post-construction stage laser scans can be utilised to capture the as-built state of the built assets. This ensures that the asset measurements are accurately taken. As part of BIM level 2 standards which have been mandated in the UK, as-built models are to be shared with the client during the handover stage for the maintenance of the asset. The process of creating these 3D BIM as-built models can be extremely time-consuming and would require resources meaning more costs for the project. Tang et al (2010) describe how laser scanning can be used to create these as-built virtualisations of the assets which will capture more accurate measurements of the physical assets in a shorter period while saving costs for resources (Tang, et al., 2010).

The interviewees have admitted that despite most of their projects implementing point clouds and digital surveys, only the digital teams within their organisation are fully utilising the technology for its benefits. This goes in line with Tang et al (2010), however, the challenges that were being faced 10 years ago as suggested by Tang et al are still present within industries where the technologies are not being used to their full potential as cited by PARE2. As they discuss the challenging aspect of managing point cloud survey data and BIM as there is a lack of awareness of uses and benefits across the different teams within organisations, it is suggested that more research be conducted on as-built point cloud survey creations, this can raise awareness across the industry.

6.3.INDUSTRY 4.0 AGENDA MATURITY MODEL

The maturity model has been implemented in this research to analyse the level of implementation of Industry 4.0 agenda within the UK's infrastructure sector which was demonstrated in Section 6.2. The maturity model will evaluate the capabilities of the organisations that took part in this study in terms of implementation of Industry 4.0 agenda which will address the organisations' maturity. Assessing the Maturity model will allow the analysis of the organisation and see where they are at in terms of entering the fourth industrial revolution. this will demonstrate if the organisations are still using processes established in the Third Industry revolution or if they have advanced into the digital and automated world. Challenges that come with Industry 4.0 are very important to analyse and identify to allow a roadmap to be created leading to a more efficient implementation, this will allow the establishment of the relationship of the organisation's innovative performance while allowing awareness to be raised within the sector.

The aim is to evaluate the organisation’s level in terms of implementation of Industry 4.0 agenda, the maturity level was developed using the Capability Maturity Model which has been described in Chapter 4. The maturity levels have been defined through a critical literature review which is based on Capability Maturity Models which have allowed the ability to establish the necessary indicators to develop the maturity model, firstly, the proposed goals to be achieved were identified as a first step of the maturity level, an in-depth literature review was then conducted of the organisations' capabilities and digital strategy with the aid of the collected primary data, during this review, themes were observed which were characterised quantifying the results and providing proposed objectives for the next five-year period. This analysis is demonstrated in Table 6.2.

The maturity model was developed to assess the organisations positioning in terms of industry 4.0 agenda implementation. Organisations' visions and objectives were used to assess the maturity level, which was divided into four levels, the first level demonstrates low maturity, following that Levels two and three represent medium maturity while level four represents a higher maturity. The model is demonstrated in detail in Table 6.3 with descriptions of each level also explained and accounts for the six key Industry 4.0 technologies that were mainly implemented derived from the primary data. The primary data from the participants and their organisations were used to assess the organisations' vision for the future and current state to assess their maturity level. The Maturity level will allow organisations to gain a better understanding of the level of implementation they are currently on compared to others, motivating them to progress and keep up within the sector. The organisations have low- medium maturity when it comes to industry 4.0 agenda implementation with barriers to the adoption and implementation of these innovative technologies. The small and medium-sized organisations that took part in this study sit at the very low end of the maturity model, while most of the larger organisations fall at the medium level. One large company however has been assigned to low maturity, which is very poor, two organisations however are at the highest level of maturity despite a few challenges. In addition, the results clearly show the difference between small and medium size organisations and larger organisations in the infrastructure sector as their levels are at each end of the spectrum, additionally, small and medium size organisations tend to not have the capabilities to adopt industry 4.0 agenda, this may be since Industry 4.0 agenda require a lot of investment through funding and competent staff. The SMEs within the industry may not have the capacity to obtain all requirements to adopt these strategies and gain value due to their size and revenue while the requirements are vital for a successful implementation of Industry 4.0 agenda.

Table 0.2: The mapping of the infrastructure's Industry 4.0 initiatives, innovation development goals and the indicators of Industry 4.0

Industry 4.0 agenda	Innovation Development Goals	INTEGRATION OF IDGS IN THE UK'S INFRASTRUCTURE SECTOR	Indicator
BIM	Goal 1: Digital Transformation strategy Goal 4: Government Soft landings Goal 11: Standards and Good Practice	- Support economic growth - Government Support - Government guidelines in the form of standards - Data management on Models	- Better information sharing - Quality of models (LOD) - Standards achievement on implementation
3D Models	Goal 7: Delivery Models	- Better Asset management - Visualisation - Minimise Risk by planning before construction - On-site space analysis (Space proofing)	- Level of Detail of Models
Big Data	Goal 2: Become Autonomous and have automated processes. Goal 3: Information Management Goal 10: Net Zero and the Environment Goal 8: Assurance	- Better Data integrity - Quantification of Volumes especially on projects with earthworks - Quantity Analysis - Sharing of Data - Data Review	- Information quality - Information management and databases
Drones	Goal 9: Skills	- Visualisation - Monitoring of project progress	- Investment in technology - Availability of drone photogrammetry
GIS	Goal 5: Interoperability Goal 6: Geospatial strategy Geospatial Commission	- Digitalisation of the project - Real-time space visualisation with assets - Planning process improvement	- Technology availability - Amount of information incorporated - Competent staff

Point Clouds and Digital Surveys	Goal 12: Delivery model understanding	- Existing conditions visualisation and assessment - Surrounding planning - Modelling using pre-existing data (As-Built Models) - 4D modelling with included existing conditions	- Production of Digital Survey - Point clouds availability across the organisation's projects

Table 0.3: Industry 4.0 maturity model

Industry 4.0 agenda	Level 0	Level 1	Level 2	Level 3
BIM	The organisation has no form implemented.	Level 0 or Level 1 BIM Implemented	Level 2 BIM fully Implemented	Level 3 BIM adopted and implemented
3D Models	The organisation has no form implemented.	2D CAD/drawings adopted and implemented	3D models adopted and implemented	3D smart models adopted and implemented
Big Data	The organisation has no form implemented.	Database adopted across projects to store project data	Common Data Environment adopted, and projects have smart models with useful project data integrated.	Level 2 category implemented, and data management systems and dashboards used on projects.
Drones	The organisation has no form implemented.	Strategy created to adopt the technology.	The technology was adopted and implemented on at least one of the organisations' projects.	The technology is adopted and implemented on more than one of the organisations' projects.
GIS	The organisation has no form implemented.	GIS JV maps adopted	3D GIS integrated GeoBIM	Integrated 4D GIS GeoBIM

Point Clouds and Digital Surveys	The organisation has no form implemented.	Traditional survey methods were adopted and implemented.	Point cloud and digital survey adopted.	Point cloud and Design integration; As-built point clouds adopted.

	Level 0	Level 1	Level 2	Level 3
BIM	SMO1 SMO2 SMO4 SMO5 SMO6 SMO7 SMO8 SMO3 LO4			LO3 LO1 LO5 LO2
3D Models	SMO1 SMO2 SMO4 SMO5 SMO6 SMO7 SMO8 SMO3 LO4			LO1 LO3 LO5 LO2
Big Data	SMO1 SMO2 SMO4 SMO5 SMO6 SMO7 SMO8 SMO3	LO4	LO1 LO2	LO3 LO5
Drones	SMO1 SMO2 SMO4 SMO5 SMO6 SMO7 SMO8 SMO3	LO4	LO1 LO3 LO5	LO2
GIS	SMO1 SMO2 SMO4 SMO5 SMO6 SMO7 SMO8 SMO3	LO4	LO5	LO3 LO1 LO2
Point Clouds and Digital Surveys	SMO1 SMO4 SMO5 SMO6 SMO7	SM02 LO5	LO2 LO1 SMO3 LO4 SM08	LO3

Figure 0.1: Classification of organisations that took part in the study based on the developed industry 4.0 maturity model.

6.4.SUMMARY

This chapter discusses the key industry 4.0 agenda that has been adopted and implemented within the UK infrastructure sector by evaluating the levels of implementation in the organisations. Six main Industry 4.0 agendas were identified from the primary data which were focussed on in this section which follows: (1) BIM, (2) 3D models, (3) Big Data, (4) Drones, (5) GIS and (6) Point clouds and Digital Survey. With the aid of the maturity level, it is evident that Industry 4.0 agenda is between low to medium across the identified six main areas.

Overall, the UK infrastructure sector is medium in terms of levels of implementation, despite there being six main technologies identified to have been implemented, more industry 4.0 agendas could positively impact the industry such as Artificial Intelligence, however from this study only one large organisation has started to invest in the technology. The implementation levels vary across large organisations within the sector as they have different competencies and capabilities within each organisation, however small to medium size organisations appear consistent in having low implementation levels. The results show that government mandate technologies have a high such as BIM which includes 3D models and Data, it is evident that large organisations consider the government's mandate and follow standards meaning the implementation of Industry 4.0 agenda. This is the reason why some organisations are ranked Tier 1 contractors as their performance has been seen by clients as improved due to new processes creating competition for other organisations.

This chapter can provide knowledge and benefits to a range of parties that are interested in Industry 4.0 agenda and the infrastructure sector. The following implications should be acknowledged:

Theoretical implications

This chapter explores specific and main Industry 4.0 technologies within the infrastructure transport sector. this allowed the focus on key technologies that have been implemented and technologies that are being overlooked within research as the infrastructure transport sector lacks research specifically tied with Industry 4.0 agenda. The proposed Maturity model can be used as a tool for future research on Industry 4.0 agenda, in addition, the model can be improved to include other Industry 4.0 agenda that may provide more insight.

Managerial implications

This chapter provides organisations with an insight into Industry 4.0 agenda across their sector. The beginning provides highlights on the technologies mostly adopted within organisations in the sector and which technology implementation to focus on to be competitive in the industry. This can assist senior management to take more initiatives in investing in Industry 4.0 agenda as it identifies areas where other organisations are excelling and what is being used to achieve that excellence.

To conclude this chapter, below are recommendations presented to the government, the industry, and Organisations within the sector to act upon:

- Government: The UK Government should create audits on organisations since the BIM mandate and ensure standards are being met and implemented in the right way across the sector. In addition, creating standards for more Industry 4.0 agenda like the BIM mandate can push organisations in the sector to implement more Industry 4.0 digital and automated processes.
- Industry: The UK infrastructure sector should review their projects and organisations' level of implementation of not only BIM Level 2 mandated standards but also industry 4.0 agenda such as AI which can advance the sector which can lead to a boost of economy changing the UK infrastructure sector's status.
- Knowledge Share: Large organisations in the sector have a medium to high level of implementation while small to medium size organisations have a low level of implementation, this shows that there is a substantial gap in knowledge within the sector. There is a need for knowledge to be shared within the sector sharing lessons learnt and best practices from organisations at an essential high level.
- Organisations: Organisations within the UK infrastructure sector should push to raise awareness both up and down the chain within their staff to ensure that all staff are capable and consider investment in necessary resources to implement Industry 4.0 agenda successfully. Organisations should create digital strategies and if already created then enhance their digital strategy to a greater level.
- Senior management: Technology is advancing every year, hence there should be continuous upskilling for all employees throughout the organisation. In addition, software and technologies invested in are to be kept up to date to keep up with newer capabilities that can positively impact the organisation.

CHAPTER 7: ANALYSIS OF THE KEY CHANGE MANAGEMENT STRATEGIES IMPLEMENTED WITHIN ORGANISATIONS TO MANAGE INDUSTRY 4.0 AGENDA.

7.1. INTRODUCTION

In this chapter, the analysis of the key change management strategies adopted by the UK infrastructure sector to accommodate the implementation of Industry 4.0 agenda are explored. This chapter answers the eight-research question which is:

"What are the key change management strategies being implemented within organisations in the infrastructure sector to manage Industry 4.0 agenda issues?"

The results presented in this chapter are based on the data collected from 21 experts from 13 different organisations within the UK infrastructure sector. The conclusions of this chapter are built from the interviewees' opinions and validated with literature, the findings from the interviewee's opinions were then mapped into McKinsey's 7S model which has not been explored before in available literature.

The findings in this chapter have been divided into two stages, the first being the identification of the key change management strategies through thematic analysis built on the interviewee's responses and the second, the mapping of these themes against McKinsey's 7-S model. This allows the understanding of the change management implemented within the sector and approaches that can lead the sector's management. Weaknesses are also highlighted through the mapping process regarding change management on Industry 4.0 agenda. The chapter then concludes by providing a summary of the findings with recommendations.

7.2. KEY CHANGE MANAGEMENT STRATEGIES IMPLEMENTED BY THE UK INFRASTRUCTURE SECTOR

This study identifies three key aspects as the main change management strategies that have been adopted to drive a successful Industry 4.0 agenda implementation. These change management strategies were (1) People, (2) Tools/Technologies, and (3) Strategy. These aspects have been explained in more detail in this chapter.

7.2.1. PEOPLE

Industry 4.0 agenda implementation is mainly dependent on the people and employees of an organisation. Organisational change can produce difficulties for all members within the organisation as there can be a lot of frustration with new practices and doubts about the change, employees can have many fears as new changes mean facing new practices. Stachowicz et al (2021) argue that competency is lacking in terms of Industry 4.0 Strategies within Polish enterprises as staff members need the education and training required to adopt these technologies and put them to use gain benefits for enterprises (Stachowicz, et al., 2021). Stachowicz et al (2021) suggest that the new processes that are introduced with industry 4.0 strategies and applications require upskilling and training to increase competency as the new processes introduce unknown and unfamiliar ways of working. Therefore, the change in people's outlook and processes is an essential step in safeguarding a successful implementation of Industry 4.0 agenda. Interviewees in this study have identified that changes are being implemented in terms of employees and staff which is mainly focussed on training and upskilling, for instance, Interviewee PARE4 explains what changes their organisation has implemented in terms of the supply chain, Interviewee PARE4 states:

> *"We are looking into the supporting of the supply chain by creating reports and training from many aspects to raise the skills set of our supply chain and staff."*

It is apparent from the interviewee's statement that organisations are working to upskill their entire supply chain to implement and adopt Industry 4.0 agenda which is vital. The change in employee competency can determine a successful adoption of Industry 4.0 agenda which involves employees with limited knowledge of the digital and automated processes introduced by Industry 4.0 to advance their skills and knowledge to understand these new processes. Torok (2020) argues in their research study that training and upskilling change management needs to be implemented to successfully adopt industry 4.0 strategies and applications (Torok, 2020). Torok (2020) emphasizes that for innovative practices to be adopted, the development of competencies within staff can promote the adoption of Industry 4.0 agenda with employees as it can enable easier adoption of the environmental changes. As

Industry 4.0 strategies are in their infancy within the infrastructure sector, many members within the sector are not competent in the new process and ways of working. Due to this training is required across the organisation including the entire supply chain needing to be upskilled to fully adopt these new strategies and gain the most benefits that are available. Interviewee PARE5 also argues that training is key to change management within their organisation and states:

> *"I started on this project a few months ago but there is a push for people to get BIM certified encouraging more awareness by training our staff members."*

The analysis of Interviewee PARE5's statement suggests that due to the UK government's BIM mandate, organisations are aiming to get their staff members BIM certified through the introduction of training to raise awareness throughout the supply chain. There have been many models created to outline processes of change management which have been stated by Lewin (1951), where Lewin has suggested that for change to occur, it is highly important to alter the mindset of the members involved in this change (Hussain, et al., 2018). During change, the main mission of organisational leaders and managers is to guide the organisation through the transition from current practices to the desired changes practices (Galli, 2019). Lewin proposed a three-step model to assist in organisation change (Galli, 2019), this was built on by John Kotter (2012) where Kotter created an eight-step model to manage the change process (Hamdo, 2021). Kotter's model includes key steps for organisations implementing a change and describes how to manage change within the organisations, this includes building a team for guidance and communication for buy-in from the staff and employees as the more communication the more understanding of the new innovative processes. Interviewee PARE3 provides an example within their organisation, PARE3 cites:

"We have a BIM upskilling portal which is available for staff across the business".

To analyse interviewee PARE3's statement, organisations have adopted tools to enable the supporting the upskilling of employees on the new Industry 4.0 technologies adopted. In addition to the training to be provided by the organisation, funding is also provided to invest in the tools necessary to allow a successful implementation of Industry 4.0 agenda. This change is vital as upskilling and training staff requires investment in tools and training which can be costly for trending technologies as the skills and competencies may be rare and have limitations to the availability of training professionals. Connelly (2020) studied an organisation who have implemented Kotter's eight-step model for change management, Connelly noted that when workers were questioned on what change they have had that was managed well and why it was managed well, the main responses highlighted that the changes were managed well as there were set goals to adhere to, in addition, the panning of the change was executed well and there was a lot of communication on the change which allowed them to understand and be prepared on how the change would affect them and alter their roles and responsibilities where their changed roles and responsibilities have been clearly defined (Connelly, 2020).

In summary, employees and staff are among the key changes adopted in the UK infrastructure sector to manage the adoption of Industry 4.0 agenda. The main changes to people that organisations have implemented are providing training and upskilling their staff to raise awareness and understanding. However, despite training being introduced to increase competency, not all organisations view the investment in training as worth it. In addition, higher management needs to support the changes which is essential for implementation to be efficient within the organisation. Furthermore, the successful change in processes requires communication and transparency throughout the supply chain to allow the understanding of these changes throughout the organisation, this also allows the sharing of knowledge between organisations and their employees improving the implementation process of Industry 4.0 agenda.

7.2.2. TOOLS/TECHNOLOGY

The concept of Industry 4.0 is surrounded by technological advances and digitisation, due to this, organisations need to adopt more advanced technologies to accommodate Industry 4.0 agenda. The COVID-19 pandemic forced the majority of organisations to work from home as social distancing meant employees are not travelling to their workplace and socially distance, Javaid et al (2020) argue that due to the COVID-19 pandemic, organisations and businesses have used digital technologies for assistance through COVID-19, especially as educational tools, this is because before COVID-19, training and upskilling of staff were usually conducted face-to-face, with restrictions introduced by COVID-19, organisations adopted more technologies and digital means especially within the infrastructure sector as works carried on throughout Covid to allow the upskilling of staff and also for works to carry on smoothly (Javaid, et al., 2020).

Sahal et al (2020) suggest that for organisations to adopt and implement Industry 4.0 agenda, the suitable technology required for the Industry 4.0 agenda should be adopted and changes within the organisation introduced by the new technology should be managed (RadhyaSahal, et al., 2020). In line with Sahal et al (2020), Interviewee PARE2 cited a change in their organisation:

> *"[…] we have funding available to get the right tools to deploy the technologies which are proposed by staff."*

The analysis of the interviewee's report suggests that their organisation have implemented changes in terms of tools investment by introducing funding to encourage Industry 4.0 innovative technologies and applications being adopted within their organisation. In other words, organisations within the sector are implementing changes to the available tools within their projects where funding is available to adopt these new tools and technologies. Following this, Manavalan and Jayakrishna (2019) argue that it is vital for organisations to accept the changing technology which can aid in the changes with sustainability and environmental changes of the product/asset, implementing these changes can enable challenges within the sector to be overcome. In addition to this, one of the key change management strategies adopted by the sector which has been highlighted in this study is the training and upskilling of staff, this is a vital change however, upskilling members of the organisation alone would not impact the adoption of industry 4.0 agenda as a standalone change management strategy (Manavalan and Jayakrishna, 2019).

The raising of awareness and upskilling of employees and the supply chain of an organisation goes together with technological changes within an organisation, as without the technological changes, the knowledge and awareness improvement within an organisation would not accelerate the adoption of industry 4.0 agenda without the technologies available within the organisation or business. Bilgen (2021) asserted that for businesses and organisations adopting Industry 4.0 agenda, it is vital that a technology adoption roadmap is to be created as this can massively impact the accomplishment of the revolution for the business. Businesses need to first define and develop the technologies intended to adopt, furthermore, a sufficient level of technology must be identified to accommodate the level of competencies and capabilities within the organisation (Bilgen, 2021).

7.2.3. DIGITAL STRATEGY

Horvath and Szabo (2019) assert the need for a digital strategy within organisations adopting industry 4.0 technologies, however, Horvath et al suggest that the need for a digital strategy has very little importance depending on the organisation size (Horváth and Szabó, 2019), Hovarth and Szabo stress the need for more than a digital strategy as Industry 4.0 agenda adoption requires staff to fully implement the processes to achieve successful adoption. Despite this, a digital strategy can allow guidance and provide a plan to senior management and leaders within the organisation to set out a plan as there is a plan in place for the organisation in terms of digital strategies. In this study, eight small to medium size organisations took part, they highlighted that there is no need for a digital strategy within their organisations as they do not foresee a return on investment, this goes in line with Hovarth and Szabo (2019) who have suggested that for small and medium-sized businesses, view digital strategies as a strategy of very low importance, however larger organisation view strategies as a set plan for innovation within their organisation. For instance, Interviewee PARE1 cites:

> *"[…] we are working on the same idea for GIS, we have also had a restructure within our organisation, and we have a digital strategy."*

Analysing the interviewee's statement demonstrates that Organisation B is going through a restructuring which shows that specific positions are being created within the organisation to accommodate Industry 4.0 agenda. Most large organisations introducing digital strategies require leaders that have the capabilities and competencies to lead the adoption of Industry 4.0 agenda, positions such as Chief Digital Officer and Digital Leads, in addition to this, organisations have also introduced Digital sectors within their organisation consisting of a team of digital experts for their projects allowing competent staff throughout their projects. Interviewee PARE1's organisation also aims to implement a digital strategy with digital solutions which can enable future infrastructure to be sustainable and efficient throughout its lifecycle. Mubarak and Petraite (2020) also argue that organisations that implement digital strategies encourage a smoother adoption of digital solutions and automation (Mubarak and Petraite, 2020). Mubarak and Petraite (2020) suggest that new technology adoption for an organisation can prove challenging as it is not an immediate process to adopt new ways of working. Developing a strategy can allow organisations and their employees to have guidance on how to implement and adopt these technologies in the right way to gain the most benefits available. In line with Mubarak and Petraite (2020), Interviewee PARE6 expresses the implementation of strategies within their organisation to accelerate the adoption of data and automated processes, Interviewee PARE6 states:

> *"In short we have developed training and developed the IMS to manage the change, that is the only change management I have noticed really."*

The analysis of the interviewee's statement shows that organisations are adopting strategies to manage changes introduced by Industry 4.0 agenda at a high level. The interviewee's organisation has developed an Information Management Strategy (IMS) which has been introduced to guide employees throughout the organisation of the processes and changes in day-to-day workflows that are introduced through the adoption of Big Data and automation. Castelo-Branco et al (2019) assert the need for businesses to develop strategies as the first stage of industry 4.0 agenda adoption and implementation, according to Castelo-Branco et al (2019), this is the first dimension of industry 4.0 agenda adoption as it changes how organisations develop their strategies with the introduction of new processes (CasteloBranco, et al., 2019). Digital strategies allow employees to gain digital knowledge as it provides a set of plans to adopt new processes, and it allows employees to gain knowledge and understanding of the skills and competency required to adopt the proposed new agenda (ETTAIBI and Bouchaib, 2021).

Mubarak and Petraite (2020) assert that technology adoption is not an easy adoption for organisations, furthermore, the adoption process is not immediate as time is required to fully deploy these technologies throughout the organisation. In addition, the production of a technological adoption strategy is essential as it allows organisations to analyse the suitability of these technologies the organisation, this enables the organisation to understand their capabilities and what technologies they are capable of adopting, furthermore, they can analyse and assess which technologies they are ready to adopt and which would need more investment and increase of knowledge within the organisation to adopt and implement at a later time when capable (Mubarak and Petraite, 2020). Despite the benefits that digital strategies can provide, Muller et al (2021) argue that for some organisations, regardless of a strategy being put in place, organisations still struggle to implement Industry 4.0 agenda within the infrastructure sector, this is due to the limitations of knowledge across all members of the organisation (M.Müller, et al., 2021).

To summarise, organisations within the UK infrastructure have adopted digital strategies in the hopes of a better adoption and implementation process of Industry 4.0 agenda. Despite the introduction of digital strategies to accelerate industry 4.0 agenda implementation, there are still limitations as the creation of a digital strategy at a high level may not be implemented down the chain as there is a massive lack of understanding at lower levels of the organisation throughout employees of these new technologies and processes. It is suggested that better understanding is pushed throughout the organisation of Industry 4.0 agenda which can lead to the digital strategy making a difference in the implementation process as all staff and supply chain can gain benefits from understanding these new processes and ways of working.

7.2.4. PROCESSES

The infrastructure sector is highly dependent on processes whether production or nonproduction, Zoubek and Simon (2021) argue that Industry 4.0 combines new technologies into the daily functions of a process and alters the normal non-production and production processes, these new processes introduce automation, digitisation, and robotics within a business (Zoubek and Simon, 2021). Industry 4.0 introduces independent systems to conduct tasks such as information exchange, Zoubek and Simon (2021) however assert that for a business to implement Industry 4.0 strategies successfully, there is a requirement to introduce new processes and avoid the processes being used so far. COVID-19 pushes all businesses across the globe to change their day-to-day processes and ways of working, as technologies were introduced to carry on work especially within the infrastructure sector as work carried on throughout COVID-19, Khan (2021) argues that COVID-19 has enhanced Industry 4.0 agenda adoption in India as where businesses are changing their processes introducing digitalisation processes within their day to day working life (Khan, 2021). This has been a worldwide influence as with the restrictions introduced due to COVID-19, businesses globally had employees mostly working from home, these restrictions forced organisations to take steps in transforming their processes and business.

Due to the restrictions, organisations in the infrastructure sector saw a change in the working environment as most staff members within the sector started working from home to adhere to UK Government rules. Industry 4.0 technologies then started becoming utilised more and the change in the work environment where employees are working from home integrated very well with the changes introduced by Industry 4.0 agenda. Within the sector, employees within organisations have been offered the opportunity to get desks and chairs sent to them to ensure that they are working in a comfortable environment and ensuring that employees have the right equipment to be able to work from home. In addition to changes in the work environment, organisations have implemented Industry 4.0 agenda to allow the connectivity within their project members for work to be carried on efficiently. Due to this, the infrastructure sector has massively changed its processes as their organisations become more digital, for instance, PARE13 asserted the following:

> *"[…] We have worked from home throughout COVID-19 and still work from home to date. My organisation had allowed certain staff members, who do not need to physically be on site, to work remotely for the foreseeable future and do not plan on all staff within projects to return to the offices post-COVID-19".*

This is a clear example of change in the work environment which in line alters the processes adopted by an organisation. Before COVID-19, meetings are usually held in person where staff will travel to the site, with the new working environment and processes, meetings are now mostly held digitally regardless of whether staff is in the offices or working remotely. This also allows more Industry 4.0 agenda to be implemented as especially for the infrastructure sector, designs and drawings are key to construction, in addition to this the availability of these designs and drawings needs to be provided in real-time to avoid working on superseded data. During the Pandemic, Organisation C along with software developers developed a new connect communications and visual platform. As mentioned, BIM is implemented within all the organisations that took part in this study, however having one platform centralised for communications and visualisations of knowledge and data has not been implemented widely throughout the industry. Covid-19 has encouraged Organisation C to assist in the production of this software. This was developed during the summer of 2020 and has now been deployed on one of their projects where it is being used. In line with the response from the participants, Bulent et al (2021) emphasize that globally, businesses are moving towards industry 4.0 agenda, however, COVID-19 have created a rush for the implementation of these strategies (Bülent, et al., 2021). There is a sense of responsibility with businesses during COVID-19 to carry on work, furthermore, within the infrastructure sector, projects are high in cost, hence any halt in works can lead to delays which can cost millions, PARE2 highlights changes within certain processes due to COVID-19 and the introduction of Industry 4.0 agenda, PARE2 cites:

> *"We have had to change many processes in terms of management, for one we have had many new starters which became a challenge for managers as new starters require inductions and training to gain knowledge about the project and job. Covid-19 has led us to use digital means for this as we have pre-recorded training and inductions for all new starters providing them induction packages of videos to watch during their initial days of starting on a project."*

Interviewee PARE9 added:

> *"With Covid-19, we have been more focused on changing business processes from traditional methods to more digital and efficient methods, the advantage we have found is that with the adoption of digital methods, we can all work from home and still share knowledge which is proving more efficient that when life was normal as we have found when people have the opportunity to speak to people and gain information face-to-face in offices that knowledge being shared in that conversation tends to not be stored and shared."*

The analysis of PARE2's statement highlights processes such as management styles and employing new staff have changed drastically and are more digital due to the impact of COVID-19. PARE2 is a part of Organisation B, the interviewee details that training material, induction videos and useful information and knowledge are stored allowing all members of the organisation access to this knowledge. First Organisation B analysed and understood the crisis to produce a fitting response to the pandemic. As the guidelines were set and represented by the UK Government, this allowed the organisations to then initiate a response phase where though there were and still are a lot of uncertainties, the recovery phase was introduced to account for the chaos in the form of turning to digital means to manage projects and staff. Several academics have supported these arguments, however, there have still been challenges noted during the transition to adopting these new processes (Bülent, et al., 2021), Nedelko and Potocan (2021) argue that despite technologies being adopted due to COVID19, this does not mean that the implementation of Industry 4.0 principles are being fully adopted along with the technologies (Nedelko and Potocan, 2021). Furthermore, organisations within the infrastructure sector seem to adopt and implement the basic and well-known Industry 4.0 strategies such as BIM, 3D Models and Drone footage, just to name a few. More efficient processes and ways of Automation such as the use of Artificial Intelligence and Augmented Reality have a very low adoption rate within the sector which can be improved on.

7.3.MAPPING AGAINST MCKINSEY’S 7-S MODEL

McKinsey’s 7-S Model has been used in this study to provide a theoretical basis for the study of industry 4.0 agenda adoption within the UK’s infrastructure sector. McKinsey's 7-S Model is established with the concept of management by setting objectives, McKinsey's model presents seven factors that act as the main variables that can affect change within an organisation namely, Shared Values, Strategy, Structure, System, Staff, Style and Skill (Chmielewska, et al., 2022). Chmielewska et al (2022) argue that an organisation's performance is dependent heavily on these seven variables highlighted by McKinsey's model and can accelerate a change in business practices as the interaction between these variables is vital. This is mainly because changes within organisations are highly dependent and focus on the organisation itself and changes implemented to accommodate the new processes. The findings of this study support the suggestions of the author as organisations within the sectors such as Buildings and Mechanical have managed to incorporate changes introduced by Industry 4.0 agenda, an important finding within this study is that organisations within the infrastructure sector have aligned views on changes applied to accommodate industry 4.0 agenda as despite not all organisations that took part in the research have developed a digital strategy, however, all organisation have digital strategies in their vision as something to be developed in future or they already have one developed.

Organisations need to have this vision as it enables organisations to understand the end goal of the changes being made. Furthermore, the introduction of a digital strategy allows changes to stem from senior teams within the organisation as they get involved in its development, allowing the information and change requirements to be fed down the supply chain and essentially advancing the organisation's culture towards innovation and entering the fourth industrial revolution. Industry 4.0 aims to transform the industry and organisations which means strategies should be involved in considering current positions and new positions to be created to adapt to the changes which affect the style the leadership of the organisations' vision, defining structures allows the definition of roles and responsibilities within the new processes, systems in the case of industry 4.0 agenda takes an important role as it introduces the new procedures and would outline the technologies. Systems influence the adoption and the availability of tools to adapt to the change is vital for Industry 4.0 agenda, with new systems and procedures in place, the skills of staff are to be enhanced to improve their capabilities. Finally, shared value within the organisation allows a smoother adoption of new processes and change as if all members of the organisation have the same vision and goal this can benefit the organisation in terms of understanding.

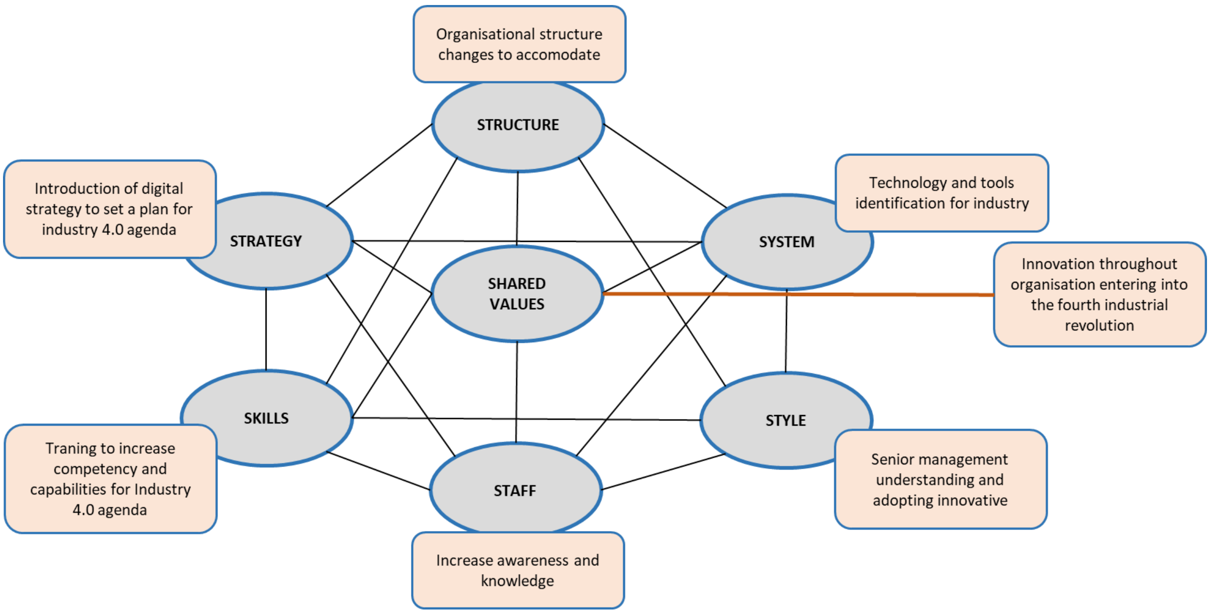


Figure 0.1: Representation of mapping the change model with change management practices implemented in the UK infrastructure sector using McKinsey's 7-S Model

7.4.SUMMARY

This chapter highlights the key change management strategies implemented by the UK infrastructure sector to adjust to the changes produced by Industry 4.0 agenda adoption. Three key change management strategies have been identified which are: People, Technologies, Strategies and Processes.

This chapter can be beneficial to several parties that are interested in Industry 4.0 agenda and the change management strategies which have been adopted. The following implications have been identified:

Theoretical implication

This chapter highlights certain change management strategies that are of importance for organisations within the infrastructure sector adopting and implementing Industry 4.0 agenda. This has not been produced before in relevance to the infrastructure sector based on researchers' knowledge, in addition, McKinsey's 7-S model is very informative and outlines starting points for further research focusing on the model being applied within the infrastructure sector.

Managerial implications

This chapter outlines the key change management strategies that organisations have or wish to implement and find useful for industry 4.0 agenda adoption. Understanding these aspects could allow organisations to implement changes within their process to allow a smooth adoption of Industry 4.0 agenda. In addition, the outcomes of this chapter can allow higher management to take into consideration aspects that have been unnoticed during the implementation of these procedures.

Key recommendations have been derived for organisations to take into consideration:

- People: The organisations within the infrastructure sector should ensure that their staff are upskilled and trained to increase competency throughout the organisation, especially from higher levels of management, this will allow the competencies and capability of the organisation to be in line with the new procedures.
- Technologies: To achieve a full and successful implementation of Industry 4.0 agenda, there is a need for the technologies and right tools to be made available. This will support the staff as they train to enhance their skills and competencies while using the available tools and technologies.

- Strategy (Digital or Innovation): Organisations should ensure they have a strategy in place this allows readiness and acceptance from higher levels of management within the organisation creating a set plan of innovative procedures and what problems and challenges they can resolve through the adoption of Industry 4.0 agenda. This allows staff to visualise the vision of adopting Industry 4.0 agenda creating a vision for the entire organisation.
- Processes: Organisations and leaders within the sector should ensure that the new processes are spread across all members within the organisation which can benefit the transitions stage to the fourth industrial revolution, in addition, organisations should contemplate changes in the work environment due to industry 4.0 agenda and ensure communication to staff is clear and there is transparency within the organisation.

The trend within the sector seems to show that organisations seem to invest in technologies/tools and digital strategies to encourage the adoption of industry 4.0 agenda within their organisation, however, the people and processes aspect seems to be lacking as organisations face challenges with guidance for the new processes, hence affecting the people. It is recommended that organisations should first outline the new processes and ensure their employees understand them. This can enable the gap between people and processes to be closed within organisations, hence securing a successful implementation.

CHAPTER 8: ANAYSIS OF THE MAIN CHALLENGES FACED IN IMPLEMENTING INDUSTRY 4.0 AGENDA

8.1.INTRODUCTION

This chapter explores the key challenges identified within the infrastructure sector when implementing Industry 4.0 agenda. This chapter tackles the sixth and seventh research questions:

> ***"What are the main challenges the infrastructure sector faced by organisations when implementing Industry 4.0 agenda?"***

And

"What is the most influential challenge that the infrastructure sector face in implementing Industry 4.0 agenda?"

The six main challenges that have been identified and presented: (1) Software and hardware, (2) Knowledge and understanding, (3) Organisation Culture, (4) Resistance to change, (5) Competency and Capabilities, and (6) Funding and Investment barriers. These have been split into sub challenged as presented in Chapter 4, Section 4.5, Table 4.4. Each challenge is expanded on separately in this chapter.

8.2.SOFTWARE AND HARDWARE (INTEROPERABILITY))

As Masood and Egger (2019) mentioned there are a lot of interoperability barriers that come with industry 4.0 strategies, software capabilities and competency within the sector is a major struggle as users will not have knowledge for example be able to adapt to user interface of the new software's and hardware (Masood and Egger, 2019). Panettoa et al (2019) also highlighted challenges such as interoperability. Panettoa et al (2019) stress the importance of interoperability in terms of cyber-physical manufacturing enterprises not just between software and hardware but interoperability between humans and machines for technologies such as Artificial intelligence which may need human-to-machine interaction (Panetto, et al., 2019). In line with Panettoa et al (2019), interviewee PARE17's statement, it is revealed that there is a clear lack of availability of software and hardware throughout the organisation which is obstructing the adoption and implementation of Industry 4.0 agenda. Masood and Egger (2019) argue that the use of the Technology-Organisation-Environment (TOE) framework which is a framework that was created based on information systems on the adoption of new technologies was developed by DiPietro et al (1990) and covers the adoption and implementation of industry 4.0 agenda which sees to overcome challenges and includes environmental challenges (DePietro, et al., 1990). Masood and Egger (2019) stress the challenges that are caused by hardware and software issues which affect the entire implementation process (Masood and Egger, 2019). This suggests that the UK infrastructure sector can benefit from frameworks such as TOE which can provide clear guidelines on the adoption and implementation of Industry 4.0 agenda. Similarly, Interviewee PARE2 noted challenges in the form of data interoperability which affects software and hardware's working together:

> *"Our organisation however is mainly used for buildings due to interoperability within our sector, we first need to ensure we have the data we require to use these technologies in our sector however it is still very manual in terms of data in the infrastructure sector."*

To expand on the interviewees, view on interoperability, Interviewee PARE2 has expressed that technology currently within their organisation is used differently in different sectors of their organisation as other sectors use different software which works together in a better way such as the building sector. Within the infrastructure sector interoperability is a lot harder especially within the rail and highways sector as the assets being constructed are linear and contain many disciplines where much different software to be used to create these assets virtually due to not one software having the capability to digitise every discipline within the infrastructure project. Interviewee PARE13 noted that there is a lack of licences for staff:

> *"On the project, I am working on we have the software available however we are lacking licences for all staff, some organisations only pay for a limited number of licences where not all staff have access to fully adopt the technology."*

The statement of the interviewee suggests that some organisations do have Industry 4.0 agenda and relevant software, however, these technologies usually require licences per staff to allow the use of the software and technology. The interviewee expressed that the current project they are working on is a Joint Venture (JV) this means that more than one organisation has been appointed to the contract where they work together to complete the project. Joint Ventures can create issues with software available as different organisations despite working on the same project will have different numbers of licences for their organisation and different software available for installation. This affects the entire project to have the same capabilities available to enhance digitisation within the project. In agreement with Kunznetsov and Dahlman (2008), in Mexico, knowledge-based innovation is lacking in terms of adoption and implementation. - Kunznetsov and Dahlman (2008) explores firms in

Mexico's performance in terms of innovation and found that most organisations depend on foreign software licenses where these are limited which limits the full implementation of knowledge-based data technologies (Kuznetsov and Dahlman, 2008). Wollschlager et al (2018) expand on interoperability issues in line with Interviewee PARE13's statement above, Joint venture technology implementation can be a big barrier as the integration of IT systems at an organisational level can require the IT systems to configure and federate to operate as a single integrated IT system. Organisations tend to have networks which impact the company and their projects massively, this causes difficulty for each organisation's network and IT systems to communicate. Most JVs produce an entirely new network for the JV which includes all organisations, however, employees may still experience interoperability issues as employees get provided IT equipment by their Parent company which may not be equipped to accommodate the new network and IT technologies (Wollschlaeger, et al., 2018).

In summary, when organisations decide to adopt and implement Industry 4.0 agenda within the infrastructure sector, the availability of the right software and hardware is essential before the commencement of projects, this will allow a smoother and more efficient Industry 4.0 adoption and implementation. As explored in Chapter 5 one of the key motivators for Industry 4.0 agenda within the sector is client demand, therefore clients demanding Industry 4.0 agenda will require their appointed contractors to have the required software and hardware. Without the IT requirements, organisations can lose their competitiveness and decrease their work winning within the organisation.

8.3.LACK OF KNOWLEDGE AND UNDERSTANDING

Ghadimi et al (2022) argue that for Industry 4.0 technology's successful implementation, the risk factors should be eliminated before implementation which includes social risks. The main social risk highlighted was employee position as an employee corporation is crucial for successful Industry 4.0 agenda implementation. In the case that employees do not acquire the knowledge and understanding, this can affect employees' interest in the new processes which hinders the successful implementation of Industry 4.0 agenda in the organisations (Ghadimi, et al., 2022). Interviewee PARE8 stated the challenges being faced within their organisation due to a lack of understanding within the teams. PARE8's statement indicates that there is a lack of proactive approaches in organisations to push for the successful industry 4.0 agenda implementation. The interviewee has expressed that their organisation had adopted a variety of industry 4.0 agenda, however throughout the organisation there is a lack of awareness of these technologies despite their availability. Most employees across organisations understand that processes will be changed due to Industry 4.0 agenda, however, the understanding of how the processes affect the business is not clear. In line with Hofmann and Rusch (2017), the understanding of Industry 4.0 changes is lacking throughout the industry, employees fail to understand that these new technologies do not only alter the business and its processes but also affect the roles of the employees, in general, a common definition and understanding of Industry 4.0 agenda is not agreed-upon within the industry and its relevant organisations (Hofmann and Rüsch, 2017). As Interviewee PARE8 suggests, organisations must take a proactive approach in implementing Industry 4.0 agenda, rather than await client demand to commence upskilling of staff, the organisation's current employees should be upskilled and be provided knowledge of Industry 4.0 agenda which can transform the organisation as a business as the more capable employees for these new processes, the more clients will have confidence in their appointed organisation.

Other sectors within the industry such as the Building and Mechanical sector have achieved a greater understanding of Industry 4.0 agenda as they have implemented a range of Industry 4.0 agenda successfully within their business. Organisations usually consist of many sectors and comparing the different sectors of the same organisation shows a wide gap for the infrastructure sector as the organisation mostly will invest in the technology, however, it is being utilised for specific sectors within the business with the infrastructure sector being behind. This is demonstrated by the example provided by Interviewee PARE1:

> *"[…] there are many things we can do as a team however the wider team are lacking in knowledge on this field. So, I would say the lack of knowledge is the main challenge within our organisation and projects."*

From the above statement, it is evident that the UK infrastructure sector is falling behind in terms of Industry 4.0 agenda adoption and implementation. The example provided by the employee indicates that the sector has available technology within their organisation, but with the lack of knowledge and awareness within the infrastructure sector, other sectors within the organisation mainly benefit from the Industry 4.0 agenda adopted. Laszlo (2020) stresses how important raising competency is with Industry 4.0 strategies as employees in organisations lack the understanding of how the new processes would work as the traditional approaches are to be disregarded once new strategies are adopted and implemented (Torok, 2020). This competency challenges requires organisations to upskill and provide adequate training to employees so that the investment in these Industry 4.0 strategies can be utilised in a productive way enabling benefits to be gained. Horvath et al (2019) describe the difficulty in having competent staff available for these new processes, in addition to the competency being an issue, upskilling current staff to can introduce more challenges as if there is resistance to change processes and ways of working with the employees, they may leave the job due to frustration leading to having to go through recruitment processes to get new staff who may require even more training (Horváth and Szabó, 2019).

Several interviewees have highlighted that there is a major lack of awareness among team members outside of the digital team within their organisations as not all staff have undertaken training to raise their competency and capability which leads to the industry 4.0 agenda not being fully adopted and implemented as a process within the organisation. For instance, Interviewee PARE2 stated:

> *"I would say upskilling and making people aware because there are many things we can do as a team however the wider team are lacking in knowledge on this field. So, I would say the lack of knowledge is the main challenge within our organisation and projects."*

It is clear from the above statement that some organisations are finding it difficult to spread awareness and get their staff members upskilled to manage new processes introduced by Industry 4.0 agenda. Some employees within the organisation understand these processes however without the entire supply chain on board, the implementation of Industry 4.0 is very unlikely to be successful.

New technologies introduce new processes which can be a challenge to explain and make people aware of the new way of working. These new technologies and strategies are complex in the way they cork compared to traditional practices as there may be many systems that need to be integrated with pre-existing content with the new technologies (Masood and Egger, 2019).

Senior leadership teams may also see the adoption of new strategies and technologies to be a disruptive process as staff and employees are to learn new ways of working and may need to spend a lot of time upskilling themselves, despite this Senior leadership teams tend to disregard the end goal benefits from adopting and implementing these strategies (Panetto, et al., 2019). Stachowicz et al (2021) also noted that within enterprises in Poland, one of the main barriers is the ability of competent staff to manage the new technologies and applications, especially with the implementation of Artificial Intelligence related systems and applications (Stachowicz, et al., 2021).

To summarise, the low level of awareness across the supply chain within the infrastructure sector creates a gap for organisations within the sector as this proves challenging them to establish the adopted industry 4.0 agenda and transform it into automated and digital processes. In addition to this, there is a lack of standards and guidance for adopting Industry 4.0 agenda. This makes it difficult for organisations to adopt Industry 4.0 agenda fully and successfully as the processes may be misunderstood and seen as not worth the investment, therefore organisations within the sector must understand the innovative business processes and create upskilling programs and sessions to support employees and teams within the organisation to generate and share Industry 4.0 agenda related knowledge.

8.4.ORGANISATIONAL CULTURE

Organisational culture is where parent companies are enabled to gain continual improvement and productivity. An organisation's culture being disrupted can impact the whole workforce, productivity and reputation based on how well new processes have been implemented and adopted. When implementing new processes, organisations need financial access to the technologies, hardware and software required for the industry 4.0 strategies to be implemented. In addition to this, educational resources would be required to guarantee that the Industry 4.0 strategy is fully implemented and adopted by competent people which is key to ensure that employees can support and handle the technologies enough to gain the maximum benefits and have a successful industry 4.0 implementation (Rauch, et al., 2020). Nafchi and Mohelska (2020) argue that Industry 4.0 agenda within industries are not taken into consideration at an organisational level. Nafchi and Moheslska express concerns about the organisation's readiness for Industry 4.0 agenda in terms of organisation size, innovation can assist companies to achieve analytical links connecting to financial stability for the organisation. Innovation has been proven to impact an organisation's success; however, the organisation's climate can have a substantial effect on the adoption of innovative processes being adopted within an organisation (Nafchi and Mohelská, 2020).

Interviewee PARE7 considers their organisation's culture to be one of the main barriers to the implementation of Industry 4.0 agenda:

"Culture change is all about people not whether it is good or bad, it is about the processes and people understanding these processes, this lack of understanding blocks the full adoption and implementation."

The analysis of Interviewee PARE7's statement suggests that within organisations, the people are the main aspect that can assist the full implementation of changes to the business and its processes. Currently, most of the interviewees have stated that within their organisation, Industry 4.0 agenda is adopted but not implemented consistently across projects. Interviewee PARE7's statement indicates that despite organisations within the infrastructure sector adopting Industry 4.0 agenda, the new processes are blocked in terms of implementation due to the lack of understanding of the organisational culture changes and how these can be managed. Mohelska and Sokolova (2018) argue that Organisational culture must match the business needs of the company for the adoption of new processes to be successful, there are three main organisational cultures which are (1) Bureaucratic culture, (2) Innovative Culture, and (3) Supportive Culture. All three types of cultures are vital in a company where their relationships with employees can provide a variety of results based on the culture of each employee (MOHELSKA and SOKOLOVA, 2018). Aguilar-Rodriguez et al (2021) distinguish the relationship between social cultures, industry 4.0 and organisation performance, ArguilarRodriguez et al argue that for organisations to transform to become innovative, various aspects should be considered, namely human performance and employee's culture, it is suggested that the combination of leadership, human capabilities, leadership and management, technology, and the culture of the organisation (Aguilar-Rodríguez, et al., 2021). Furthermore, Interviewee PARE7 provided an ideal scenario for operating the implementation of Industry 4.0 agenda while commenting on organisation culture challenges:

"High-level strategy and high-level ownership, what I mean by that is someone mapping out how it will happen and why it will happen from a higher level to filter it through to lower levels, for me it has to be driven down the whole system."

Interviewee PARE7 suggests that a higher-level strategy from SMT (Senior Management Teams) can encourage the adoption of these technologies and applications within the organisation. The interviewee whose organisations work as Tier 1 contractors in the UK (Organisation D) has adopted and implemented no Industry 4.0 agenda within their project. The Interviewee expressed that despite the Building Information Model being a UK government mandate for public sector projects, SMT within their organisation has not enforced and assisted in the implementation due to their lack of understanding. Santos et al (2021) argue that different cultures within organisations' employees effectively have an impact on the future of new processes as organisational culture is a key factor of the success of the respective markets such as Industry 4.0 agenda, furthermore, employee skills play a massive part in the implementation of Industry 4.0 applications. Santos et al (2021) suggest that employees and senior management and leadership teams within organisations must that the right culture to facilitate the ability to adapt to the changes introduced and challenges that are presented with the new processes (Santos, et al., 2021).

To summarise, Organisational Culture creates a gap within the infrastructure sector challenging organisations and their employees to properly implement Industry 4.0 agenda successfully. Furthermore, employees as an individual and their culture and outlook towards Industry 4.0 agenda implementation takes a massive role in the success or failure of the implementation of Industry 4.0 agenda and the new processes introduced, this makes it difficult to implement processes across the organisation. Therefore, it is suggested that organisations must understand how to motivate their employees to be open to changes of processes and manage how to control emotions and conflict or individuals and teams which can provide confidence in the new processes leading to employees having the enthusiasm and drive to implement these processes.

8.5.RESISTANCE TO CHANGE

Reyes-Veras et al (2021) highlight that resistance to change within the construction sector is a key challenge which has always been a huge issue within the infrastructure sector especially around innovation and technology. The construction industry has a lot of staff members that have been in the industry for years, due to the traditional practices and methods being used over the years, staff members resist the change to new processes and practices as they are already comfortable with the old processes that they have adopted and implemented for years. Innovative tools and processes are seen to improve the management of resources for an organisation and improve decision making however, traditional practices are known to discourage companies and employees when new methods are introduced (Reyes-Veras, et al., 2021). For instance, Interviewee PARE5 expands on the challenges within their organisation on the supply chain and their resistance to change, Interviewee PARE5 states:

> *"Getting the supply chain to be on board, such as the engineers, for example trying to get them to use even VR for training purposes is challenging due to reluctance most people always want to go back to their paper copies."*

The analysis of the interviewee's statement suggests that different members within the supply chain have different outlooks on new innovative processes implementation. Employees within the organisations that are within roles such as engineers and site supervisors mostly undertake works on site without any technology as they are involved in the physical aspects of the construction of infrastructure assets. Despite the benefits these staff members can gain with innovative processes such as using technologies like Virtual Reality (VR) or Augmented Reality (AR) which can assist in tasks such as visualising utilities underground in real-time or planning out space on site, these technologies will alter the tradition practices currently being undertaken which most staff do not see as necessary as the current practices work even though these new processes can prove to be more efficient and productive.

The scenario described above with the use of VR and AR, if not adopted results in site engineers and site supervisors needing to travel back into the offices to carry out the tasks as the technology being used in traditional practices are laptops on-site or paper copies of documents, this wastes time and cost of travel to and from the site. Aripin et al (2019) describe how a lack of knowledge and acceptance of the technologies has introduced resistance to change within the Malaysian construction industry. It was noted that 16% of the participants that took part in Aripin et al's (2019) study mentioned that there was a lack of knowledge within their organisation while 22% noted that there is individual resistance among staff members in construction organisations who are resisting the change to adopt these new technologies and way of working. The challenges in this study have been shown to relate to each other, Aripin et al suggest that the lack of understanding and knowledge is leading to resistance to change and implementing and adopting Industry 4.0 technologies and strategies (Aripin, et al., 2019).

Resistance to change also takes place at higher management levels due to the lack of understanding of these new processes. Hovarth and Szabo (2019) argue that both employee's and management's outlook on implementing new processes has a massive impact on the introduction of Industry 4.0 agenda within organisations, Ito et al (2021) also noted that resistance to change is highly affected by the role of organisational culture (Ito, et al., 2021) which has also been one of the challenges highlighted in this research study. Resistance does not always put new processes adoption and implementation to a halt, however, employees being resistant to the new processes and in addition to that, insufficient management available for these new processes introduces a major barrier (Hovarth and Szabo, 2019). For instance, Interviewee PARE2 expresses their view on different teams within their organisation and the implementation of Industry 4.0 agenda, Interviewee PARE2 cites:

"I would say people are the biggest challenge in these types of strategies, the digital team would usually think of an idea however for example the site manager will be against this as they would not want to adopt the new ways which are probably more efficient but only would work if it is fully adopted. So, when we get the people resisting this change it's very difficult to fully implement."

The analysis of Interviewee PARE2's statement that changes in new ways of working may seem daunting for employees who do not understand these new processes, the lack of understanding of these new processes leads to resistance from the workforce of organisations with the new processes. Mohelska and Sokolova (2018) argue that the changes in working practices alter the conditions of working for employees within an organisation who have adopted Industry 4.0 agenda. Mohelska and Sokolova (2018) suggest that due to these new processes and changes introduced, managerial approaches should also change to accommodate these changes, in addition, organisations' business models should change and adapt to the new processes introduced within the organisation (MOHELSKA and SOKOLOVA, 2018).

To summarise, resistance to change is a major challenge with any new process as new ways of working can be daunting for most staff as they are used to the processes that they have been used to for years. In addition, having competent people within organisations and the industry can allow these new processes to be implemented better and allow the ability to have people within the organisation who can guide others with less knowledge on these new processes. It is suggested that senior leaders and managers within organisations boost the morale of the culture change to adapt to the new working processes introduced by Industry 4.0 agenda. This will help in changing both the organisation and individual employees' culture and outlook of Industry 4.0 agenda, in addition, senior members of the organisation can encourage knowledge sharing and upskilling of the team to improve their understanding of the new processes.

8.6.COMPETENCY

Competency is a major challenge, especially for new upcoming technologies with staff members needing the training and skills knowledge to assist the organisations' goal of adoption and full implementation of these new processes and technologies. Masood et al also mention competency and lack of education of staff members being a key issue within organisations when it comes to the adoption and implementation of new technologies and processes such as Augmented Reality (Masood and Egger, 2019), Masood et al argue that the lack of competencies within the staff members provides major barriers for industry 4.0 agenda implementation as competency needs to be enhanced to allow knowledge about these technologies within the organisation members. This is not the scenario within the infrastructure sector as staff are mostly aware of these technologies, however, they tend not to be competent to adopt the processes introduced by these technologies. Interviewee PARE3 considers competence as the biggest challenge within their organisation, Interviewee PARE3 cites:

> *"The biggest challenge we have come across I would say* ***upskilling*** *and making people aware because there are many things we can do as a team however the wider team are lacking in knowledge on this field".*

To analyse Interviewee PARE3's upskilling the entire teams within the organisation is creating a barrier as the lack of understanding of these technologies leads to their implementation process coming to a halt. Industry 4.0 agenda requires the entire organisation to implement the processes to allow for a successful implementation. Similarly, Shet and Pereira (2021) argue that for organisations to fully implement and work with Industry 4.0 agenda, senior members of organisations are required to learn the new competencies and skills which can allow them to pass on those skills down the chain. Competency refers to the combination of behaviours that drive the deliverance of the chosen results where competency is formed of the knowledge, attitude, and skills of an individual (Shet and Pereira, 2021). Aripin (2019) argues that there is a need for knowledge on these technologies to be shared and retained by organisation staff members with the use of training and guidance to allow them to gain the skills required for Industry 4.0 technologies and strategies, Aripin (2019) noted competency as one of the main challenging factors influencing the implementation of Industry 4.0 technologies in Malaysia, it is suggested that for the transformation into Industry 4.0 agenda for an organisation, a specific level of knowledge is required increasing competency, this can be conducted through providing training to develop the skills required within employees and will allow the increase of their technical competencies which will increase their level of competency for industry 4.0 agenda (Aripin, et al., 2019).

Similar to Shet and Pereira (2021), Flores et al (2019) describe competency as a combination of characteristics which are ability, skill set, knowledge and experience of individuals which is necessary to perform the tasks with the new processes, however the oversight of a deeper understanding and deeper knowledge of the required attributes for Industry 4.0 competencies which can be difficult to assess and train employees of the organisation to the required skills (Flores, et al., 2019). Competency has been proven by studies to have a major influence towards motivation, commitment, decision-making, performance, and satisfaction as competency supports the control of complex activities introduced by the processes of Industry 4.0 agenda (Flores, et al., 2019)

To summarise, Industry 4.0 agenda introduces new processes and ways of working for an organisation and its employees. The combination of lack of knowledge and awareness influences the competency of employees and organisations, due to the lack of knowledge, employees do not possess the capabilities and understanding of the new processes hence a successful implementation is unlikely to take place. It is suggested that organisations within the sector should provide training to increase the competency of their employees from the senior management level and down the chain to support the teams in understanding the Industry 4.0 agenda processes and advance their skills to the required competency for Industry 4.0 agenda.

8.7.FUNDING

The implementation of Industry 4.0 agenda within an organisation required significant financial investment (Aripin, et al., 2019). Aripin et al (2019) assert technology requires investment in terms of funding due to the requirement for the technologies to be purchased, in addition, most of these technologies require licences to be purchased which are high in cost. Furthermore, Aripin et al (2019) state that besides the costs required for the technologies, costs can be higher due to the requirement for training due to the lack of knowledge of which organisations are to invest in to successfully implement Industry 4.0 agenda. Funding and investment represent an important challenge for organisations, in this study, interviewees have highlighted that funding for Industry 4.0 agenda is creating a barrier to adopting these technologies. For instance, Interviewee PARE6 stated:

> *"The biggest challenge is adoption and getting funding for the new technology despite trying to be innovative, it is a big struggle to get investment on it and rolling it out, for example, no tablets to roll out the digital forms."*

The analysis of the interviewee's statement suggests that within the sector investment in supporting technologies to accommodate Industry 4.0 agenda is lacking within the sector. This introduces a blockage on the full implementation of the technologies adopted, for instance, within the organisation of the interviewee, they have adopted mobile field technology which allows the digitisation of site forms and paperwork. This technology requires an investment in portable devices such as iPads to roll out on the team as they would require these to enable filling the digital forms on site leading to a more efficient process, however, their organisations are resistant to investing in portable devices for staff despot the industry 4.0 agenda being adopted within their organisation hence not fully implemented by projects and employees. In line Stachowicz et al (2021), argue that organisations aim to minimise the initial cost of these technologies within Polish organisations where Industry 4.0 agenda is being implemented, this is mainly because Industry 4.0 agenda requires a high upfront cost and usually takes time to gain a return in investment, due to this, organisations within the sector struggle to see the long term benefits in their investment (Stachowicz, et al., 2021). Similarly, Interviewee PARE3 gave another example like Interviewee PARE6 on the struggle in getting investment support from their organisation to push the implementation of field mobile technologies, Interviewee PARE6 cites:

> *"We as the BIM team know many software's for example Common Data Environments to adhere to BIM standards however these software's require licencing which some of our projects are hesitant to invest in".*

From the above statement, it is evident that the lack of knowledge of Industry 4.0 agenda also influences organisations providing funding for Industry 4.0 agenda. Within organisations, if the senior team who can influence the investment in Industry 4.0 agenda do not understand their processes or what is required to gain full benefits from these technologies, they will not support the funding for Industry 4.0 agenda. As the interviewee explains, the digital team within their organisations fully understand the capabilities that Industry 4.0 agenda provides for their organisation, however, with the Industry 4.0 agenda adopted on their projects, their organisation has not invested in the required licences for all staff members to be able to use the adopted technology. Reyes-Veras et al (2021) argue that companies tend to make a large investment in Industry 4.0 agenda, however, these technologies never seem to be fully adopted within the organisation, this provides less confidence to the organisations to adopt more Industry 4.0 agenda as it may seem like a waste of funding (Reyes-Veras, et al., 2021).

The interviewees have expressed the lack of funding from senior staff within the organisations to drive the new innovative technologies and processes. Within one of the participant's projects, there was funding provided for the technology and software at an organisation level, however at a project level investment was required for iPads to use the software to fill in digital forms on site. This was a struggle and at a project level, they were not approved which led to the technology and new process being introduced to be a waste of time. This is quite a common issue within the infrastructure sector as one organisation can be undertaking multiple projects at a time with different senior management, furthermore, a lot of projects are Joint Ventures where the projects are undertaken by more than one organisation, this creates a barrier as despite if one of the organisations within the joint venture have adopted and implemented industry 4.0 agenda, the other organisation within the joint venture may not have the technology available which blocks the full use of the industry 4.0 agenda.

To summarise, the cost of adopting and implementing Industry 4.0 agenda is one of the barriers the infrastructure sector faces. Industry 4.0 agenda requires a high initial cost and financial return may not be instant, therefore senior members of the organisation view Industry 4.0 agenda as a future vision but hesitate to provide funding for the technologies adoption. Most senior staff do not understand the benefits and efficient processes Industry 4.0 agenda introduces, therefore providing a clear justification will help in supporting the investment of Industry 4.0 agenda for organisations. in addition, a clear justification will provide confidence to the organisation that despite high initial costs, a realistic return on investment can be possible leading to more industry 4.0 agenda being adopted.

8.8.GRAPH THEORETICAL MATRIX APPROACH

For this chapter, a graph theoretical and matric approach has been utilized to assess the challenges that organisations in the UK infrastructure sector currently face concerning industry 4.0 agenda implementation. The Graph Theoretical approach and matrix approach (GTMA) has been selected as it allows the sub-challenges identified to be assigned to a numerical value enabling the challenges to be compared regarding the limits that they introduce in the implementation of Industry 4.0 agenda. The interviewees provided detail on how much each challenge influences their organisation with the interview question that was presented, this allowed the ranking of the challenges, below are the main steps conducted for the methodology of the analysis of these challenges:

Table 0.1: Challenges faced within the UK infrastructure sector when implementing Industry 4.0 initiatives.

Software and Hardware (SH)	- Interoperability (SH1) - Cost of software and licence (SH2)
Knowledge and Understanding (KU)	- Lack of Knowledge and clarity (KU1) -

	Lack of understanding of new processes involved with industry 4.0 agenda across the organisation (KU2) - Lack of awareness relating to Industry 4.0 (KU3) - Lack of guidelines and standards (KU4)
Organisation Culture (OC)	- Lack of support from senior staff (OC1) - Lack of engagement throughout the organisation (OC2) - Lack of clarity on goals and outcomes on adoption within organisations (OC3)
Resistance to Change (RC)	- Individually within the staff (RC1) - Group level within teams (RC2) - Organisational level (RC3)
Competency and Capabilities (CC)	- Lack of competent staff for new processes (CC1) - Lack of human resources (CC2)
Funding and Investment (FI)	- High initial cost (FI1) - Lack of funding for resources (FI2) - Long-term financial gain (FI3)

8.9.METHODOLOGY STEPS

- Identify the sub-factors that affect the main challenges identified; represented in Table 8.1.
- Develop the diagraphs with consideration of the variables and relationships that have been identified; demonstrated in Table 8.2.
- Develop matrices with the use of the created diagraphs using Equation 1.
- The matrices are then transformed into permanent functions with the use of Equation 2.

- With the help of professionals in the UK infrastructure sector, the values were substituted for variables and values ranging from 1 – 5 where 1 is very weak and 5 is very strong were applied (Rajesh, et al., 2013).
- Every challenge is then assigned a numerical value after calculations demonstrated in Table 8.3.
- Finally, the theoretical best and worst values are calculated and compared to the values derived from the calculation.

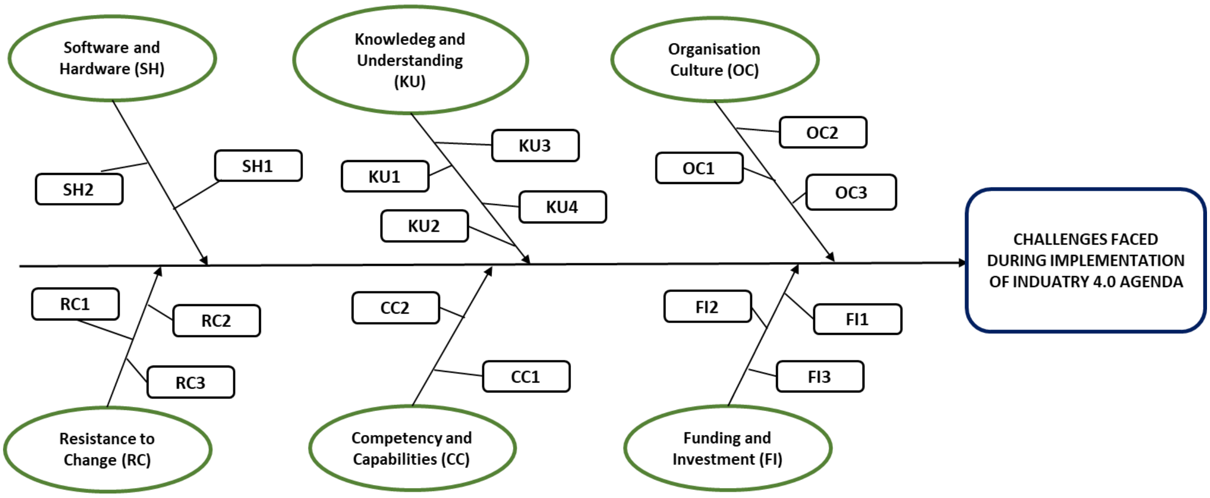


Figure 0.1: Demonstration of the challenges being faced in the infrastructure sector when implementing industry 4.0 strategies.

Table 0.2: Attributes ranking of importance demonstrated by aij

Class Description	Relative Importance of Factors	
	a_{ij}	$a_{ji} = 10 - a_{ij}$
Two attributes are equally important	5	5
One attribute is slightly more important than the other	6	4
One attribute is strongly more important than the other	7	3
One attribute is very strongly more important than the other	8	2
One attribute is extremely important over the other	9	1

One attribute is exceptionally more important than the other	10	0

Table 0.3: Measure of the attribute in qualitative form

A qualitative measure of a performance attribute	Assigned Value
Exceptionally Low	0
Extremely Low	1
Very Low	2
Below Average	3
Average	4
Above Average	5
Moderate	6
High	7
Very High	8
Extremely High	9
Exceptionally High	10

Table 0.4: Challenges and their assigned number

Challenge Number	**Challenge identified**
C_1	Software and Hardware
C_2	Knowledge and understanding
C_3	Organisation Culture
C_4	Resistance to Change
C_5	Competency and Capabilities
C_6	Funding and Investment

8.9.1. DIRECTED BEHAVIOURAL DIGRAPH

The challenges and sub-challenges identified for the implementation of Industry 4.0 agenda in the UK infrastructure sector were classified as nodes and edges as explained in Chapter 4. The factors identified are represented by the nodes and the relationship between the factors is represented by the edges. The digraph allows a visual illustration of the challenges found in this study and how they interact. The digraph is presented in Figure 8.2 where the challenges (C_1)

are the nodes ad the relationship is illustrated as (a_{ij}). a_{ij} represents the edge from node i to j. The behavioural digraph is demonstrated in Figure 8.3 where node C2 represents Knowledge and Understanding and nodes $C_1{}^2$, $C_2{}^2$, $and\ C_3{}^2$ are the sub-challenges identified, with a_{ij} being the interdependency between them.

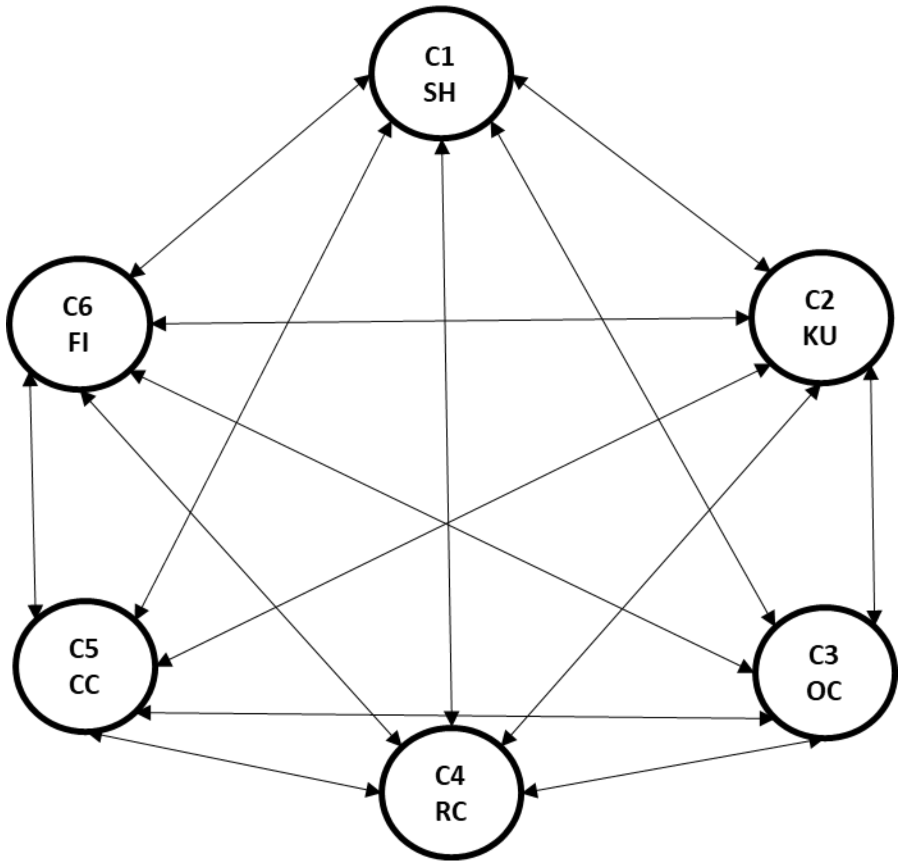


Figure 0.2: Identified challenges behavioural digraph.

8.9.2. MATRIX REPRESENTATION

The behavioural digraph is demonstrated as a 6 x 6 matrix demonstrating the six identified challenges within this study and their interrelationships. Matrix F was developed demonstrated below:

$$I = \begin{pmatrix} C_i & a_{ij} & a_{ik} & a_{il} & a_{im} & a_{in} \\ a_{ji} & C_j & a_{jk} & a_{jl} & a_{jm} & a_{jn} \\ a_{ki} & a_{kj} & C_k & a_{kl} & a_{km} & a_{kn} \\ a_{li} & a_{lj} & a_{lk} & C_l & a_{lm} & a_{ln} \\ a_{mi} & a_{mj} & a_{mk} & a_{ml} & C_m & a_{mn} \\ a_{ni} & a_{nj} & a_{nk} & a_{nl} & a_{ml} & C_n \end{pmatrix} \qquad (6)$$

C_i = Represents the value of the factors as nodes a_{ij} = Represents the value of the importance of the ith factor and the jth is represented by edges.

The matrix representing the challenge *Knowledge and Understanding* will be a 3 x 3 matrix as the challenge consists of three sub-challenges identified. This is demonstrated below:

$$KU = \begin{pmatrix} C_1^2 & a_{12}^2 & a_{13}^2 \\ a_{21}^2 & C_2^2 & a_{23}^2 \\ a_{31}^2 & a_{32}^2 & C_3^2 \end{pmatrix} \tag{7}$$

Where $C_1{}^2$, $C_2{}^2$ and $C_3{}^2$ represent the sub challenges KU1, KU2 and KU3.

Following this, a matrix was produced for all identified challenges where each challenge matrix depended on the number of sub-challenged identified n x n, with n representing the number of sub-challenges for each main challenge identified.

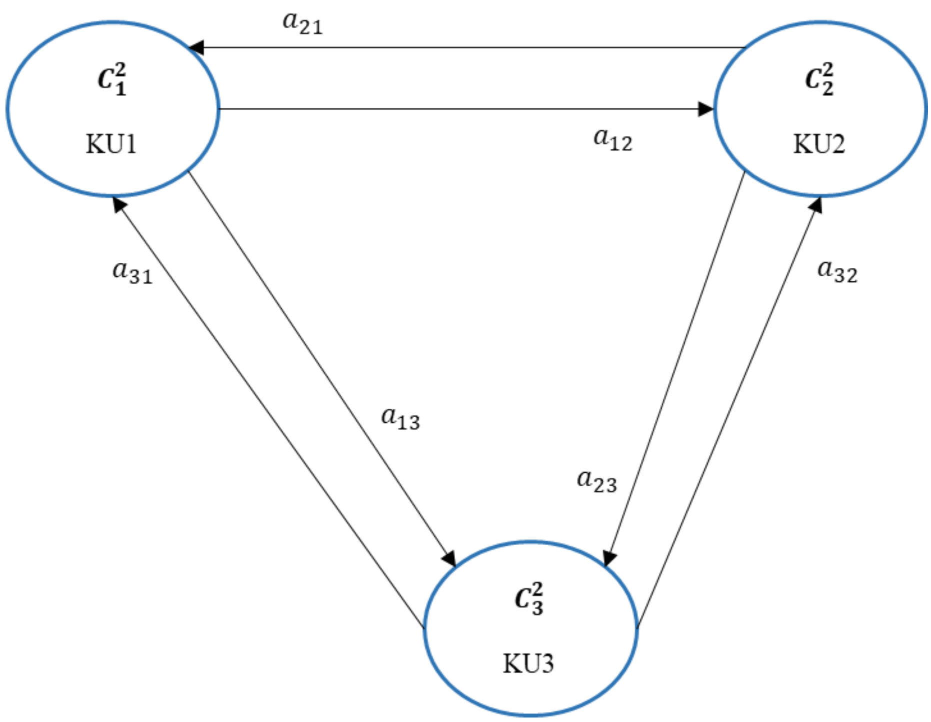


Figure 0.3: Behavioural Diagraph for Knowledge and Understanding

8.9.3. PERMANENT REPRESENTATION

The value of the permanent function represents a standard matrix function that is mainly used within combinatorial mathematics, the permanent function for this study has been calculated to find the determinant while the negative values have been changed to positive to allow the information to be maintained and achieve a better appreciation of the results (Agrawal, et al., 2016). The permanent function expression correspondent the challenges behavioural graph demonstrating the identified challenges using Jack and Ryser's (1963) formula which is as follows:

$$
\begin{aligned}
\text{Per (I)} = & \prod C_i + \sum_i \sum_j \sum_k \ldots \sum_m \sum_n a_{ij}^2 C_k C_l C_m C_n \ldots + \\
& 2 \sum_i \sum_j \sum_k .. \sum_m \sum_n (a_{ij} a_{jk} a_{ki}) C_l C_m C_n + 2 \sum_i \sum_j \sum_k \ldots \sum_m \sum_n (a_{ij} a_{jk} a_{kl} a_{li}) C_m C_n \ldots + \\
& \sum_i \sum_j \sum_k \ldots \sum_m \sum_n (a_{ij}2\, a_{kl}2\,) C_m C_n \ldots + 2 \sum_i \sum_j \sum_k \ldots \sum_m \sum_n (a_{ij} a_{jk} a_{kl} a_{lm} a_{mi}) C_n \ldots + \\
& 2 \sum_i \sum_j \sum_k \ldots \sum_m \sum_n (a_{ij} a_{jk} a_{ki}) a_{lm}2\, C_n + \sum_i \sum_j \sum_k \ldots \sum_m \sum_n a_{ij}2\, a_{kl}2\, a_{mn}2 \ldots + \\
& 4 \sum_i \sum_j \sum_k .. \sum_m \sum_n (a_{ij} a_{jk} a_{ki})(a_{lm} a_{mn} a_{nl}) .. 2 \sum_i \sum_j \sum_k ... \sum_m \sum_n (a_{ij} a_{jk} a_{kl} a_{li}) a_{mn}2 \ldots
\end{aligned} \qquad (8)
$$

This permanent function consists of n! terms which are arranged in groups represented by n+1, with n being the number of elements. Within this study, 6 challenges were identified, hence n=6, thus seven groupings were conducted explained further below:

- The initial grouping consists of the interaction of the six identified main challenges (i.e., C_1, $C2$, $C3$, $C4$, C_5, C_6).
- The second grouping is not adopted for this research as there are no identified self-loops.
- Following this, the third grouping exemplifies interdependence loops of a set of two systems (i.e., a_{ij} a_{ji}) and the effectiveness of the challenges that remain (n-2), which within this study makes a total of four identified challenges.
- The fourth grouping consists of interdependency loops of a three-system set (i.e. a_{ij} $a_{jk} a_{ki}$ or a_{ik} $a_{kj} a_{ji}$) and the effectiveness of the challenges that remain (n-3), providing a total of three.
- Within the fifth grouping, there are two subgroups where the first subgroup consists of interdependence loops of a set of two-system (i.e. a_{ij} a_{ji} and a_{kl} a_{lk}) measuring the

effectiveness of the two systems that remain (i.e. C_m, C_n). The second sub-group contains the result of the four-system interdependence (i.e. $a_{ij}\, a_{jk} a_{kl} a_{li}$ *or* $a_{il}\, a_{lk} a_{kj} a_{ji}$) and the effectiveness of the two systems that remain (i.e. C_m, C_n).

- In the sixth grouping, there are two subgroups where the terms of the initial subgroup are the creation of interdependence loops of a set of two-system (i.e. $a_{ij}\, a_{ji}$), in addition to this an interdependence loop of a set of three-system (i.e. $a_{kl}\, a_{lm} a_{mk}$ *or* $a_{km}\, a_{ml} a_{lk}$). The second subgroup consists of an interdependence loop of a set of five-system (i.e., $a_{ij}\, a_{jk} a_{kl} a_{lm} a_{mi}$) and the efficiency of the one challenge that remains (i.e. C_n).
- The final seventh grouping contains four subgroups, where the first subgroup signifies interdependence loops of the creation of two-system (i.e. $a_{ij}\ a_{ji}$) and also interdependence loops four-system (i.e. $a_{kl}\, a_{lm} a_{mn} a_{nk}$ *or* $a_{kn}\, a_{nm} a_{ml} a_{lk}$). The following subgroup consists of two interdependence loops which contain three systems (i.e., $a_{ij}\, a_{jk} a_{ki}$ *or* $a_{lm}\, a_{mn} a_{nl}$). The third subgroup is the construction of three interdependence loops where each contains two systems (i.e., $a_{ij}\, a_{ji} a_{kl} a_{lk}$ *and* $a_{mn}\, a_{nm}$). The final subgroup is an interdependence loop of six systems (i.e., $a_{ij}\, a_{jk} a_{kl} a_{lm} a_{mn}\, a_{ni}$).

The permanent function of each challenge identified has been calculated separately with the use of Equation 3 to obtain their respective C_{il} values, the calculations for each challenge; C_1, $C2$, $C3$, $C4$, C_5, C_6, are demonstrated below:

$$C_1 = \text{Per (SH)} = \text{Per}\begin{pmatrix} C_1^1 & a_{12}^1 \\ a_{21}^1 & C_2^1 \end{pmatrix} = \text{Per}\begin{pmatrix} 5 & 6 \\ 4 & 5 \end{pmatrix} = 49 \tag{9}$$

$$C_2 = \text{Per (KU)} = \text{Per}\begin{pmatrix} C_1^2 & a_{12}^2 & a_{13}^2 & a_{14}^2 \\ a_{21}^2 & C_2^2 & a_{23}^2 & a_{24}^2 \\ a_{31}^2 & a_{32}^2 & C_3^2 & a_{34}^2 \\ a_{41}^2 & a_{42}^2 & a_{43}^2 & C_4^2 \end{pmatrix} = \text{Per}\begin{pmatrix} 6 & 4 & 6 & 3 \\ 6 & 3 & 5 & 4 \\ 4 & 5 & 4 & 3 \\ 7 & 6 & 7 & 6 \end{pmatrix} = 12947 \tag{10}$$

$$C_3 = \text{Per (OC)} = \text{Per}\begin{pmatrix} C_1^3 & a_{12}^3 & a_{13}^3 \\ a_{21}^3 & C_2^3 & a_{23}^3 \\ a_{31}^3 & a_{32}^3 & C_3^3 \end{pmatrix} = \text{Per}\begin{pmatrix} 7 & 6 & 6 \\ 4 & 5 & 5 \\ 4 & 5 & 3 \end{pmatrix} = 712 \tag{11}$$

$$C_4 = \text{Per (RC)} = \text{Per}\begin{pmatrix} C_1^4 & a_{12}^4 & a_{13}^4 \\ a_{21}^4 & C_2^4 & a_{23}^4 \\ a_{31}^4 & a_{32}^4 & C_3^4 \end{pmatrix} = \text{Per}\begin{pmatrix} 5 & 6 & 4 \\ 4 & 4 & 1 \\ 6 & 9 & 8 \end{pmatrix} = 673 \tag{12}$$

$$C_5 = \text{Per (CC)} = \text{Per}\begin{pmatrix} C_1^5 & a_{12}^5 \\ a_{21}^5 & C_2^5 \end{pmatrix} = \text{Per}\begin{pmatrix} 5 & 6 \\ 4 & 4 \end{pmatrix} = 44 \tag{13}$$

$$C_6 = \text{Per (FI)} = \text{Per}\begin{pmatrix} C_1^6 & a_{12}^6 & a_{13}^6 \\ a_{21}^6 & C_2^6 & a_{23}^6 \\ a_{31}^6 & a_{32}^6 & C_3^6 \end{pmatrix} = \text{Per}\begin{pmatrix} 6 & 6 & 5 \\ 4 & 4 & 4 \\ 5 & 6 & 4 \end{pmatrix} = 676 \tag{14}$$

Upon calculation of the index values for each of the challenges identified, the industry 4.0 adoption challenge index value was calculated with the use of Equation 2:

$$\text{Per (I)} = \text{Per}\begin{pmatrix} 49 & 4 & 3 & 3 & 5 & 4 \\ 6 & 12947 & 5 & 5 & 6 & 3 \\ 7 & 5 & 712 & 5 & 3 & 4 \\ 7 & 5 & 5 & 673 & 7 & 6 \\ 5 & 4 & 7 & 3 & 44 & 8 \\ 6 & 7 & 6 & 4 & 2 & 676 \end{pmatrix} = 9.189 \text{ x } 10^{15} \tag{15}$$

Table 8.5 presents the index values that have been calculated.

8.9.4. THEORETICAL BEST AND WORST VALUES

The theoretical values were analysed and calculated further to outline the best and worst values for all the challenges identified for Industry 4.0 agenda within the UK infrastructure sector.

The hypothetical best value of each challenge was calculated, this was conducted at a sub challenge level, for example, the best value for Software and Hardware (best value being 1) was:

$$B_1 = Per\begin{pmatrix} 1 & 5 \\ 5 & 1 \end{pmatrix} = 26 \tag{16}$$

Similarly, the hypothetical best value of each challenge was calculated, this was conducted at a sub-challenge level, for example, the best value for Software and Hardware (best value being 5) was:

$$W_1 = Per\begin{pmatrix} 5 & 5 \\ 5 & 5 \end{pmatrix} = 50$$

8.9.5. COMPARISON OF FACTORS IDENTIFIED

In this study, a comparison methodology was used to analyse and compare the challenges identified in Industry 4.0 agenda adoption and implementation within the UK infrastructure sector. To achieve a better evaluation of the results the comparison allowed the unlikelihood and likelihood to be highlighted based on the best and worst scenarios to obtain the coefficients (Muduli and Barve, 2013).

To calculate the likeliness coefficient of the best-case value, the equation below has been used:

$$F_{Ii} = \frac{C_i - B_i}{W_I - B_i} \tag{18}$$

Where;

F_{Li}: The Coefficient of the likeness of the ith factor (Challenge in question) within the bestcase value.

B_i = The best value for the ith Challenges

W_i = The worst value for the ith Challenges

B_i = The calculated value for the ith Challenges

To calculate the likeliness coefficient of the worst-case value, the equation below has been used:

$$F'_{Li} = \frac{W_i - F_i}{W_I - B_i} \tag{19}$$

Where;

F_{Li}' : The Coefficient of the likeness of the ith factor (Challenge in question) within the worstcase value.

After the likeliness coefficient was calculated, the unlikelihood coefficients were calculated for the best and worst cases with the use of the following equations:

$$F_{Ui} = 1 - F_{Li} \tag{20}$$

$$F_{Ui}' = 1 - F_{Li}' \tag{21}$$

Where F_{Ui} and F_{Ui}' represent the coefficient of the unlikelihood in terms of the best and worst cases.

If the value of F_{Li} is small for the ith factor in question, this demonstrates that the best value has less impact on Industry 4.0 agenda adoption and implementation. In the case that the F_{Li}' is a smaller value, this indicates that the ith challenge in question has more of an impact as a challenge in industry 4.0 agenda implementation. The results are demonstrated in Table 8.5 highlighting the coefficients of the likelihood for the best value for the challenges highlighted in this study.

Table 0.5: UK infrastructures Index Values calculated.

	Software and Hardware	Knowledge and understanding	Organisation Culture	Resistance to Change	Competency and Capabilities	Funding and Investment
Actual Value	49	12947	712	673	44	676
Best Value	26	6776	326	326	26	326
Worst Value	50	15000	750	750	50	750
F_{Li}	0.958	0.750	0.910	0.818	0.750	0.825

8.10. DISCUSSION

The implementation of Industry 4.0 strategies index was calculated for the UK infrastructure sector to assess the readiness of Industry 4.0 agenda implementation. In addition, the index calculated proved useful as it provides a more in-depth understanding of each challenge currently being faced by the sector as it provides values and impacts numerically of each challenge. The larger index values of challenges identified demonstrate that these challenges are highly impacting and creating a barrier for organisations in the sector in terms of industry 4.0 agenda implementation. This will allow organisations within the sector to assess their position and essentially improve on aspects that are needed to be focussed on, in addition, the organisations can effectively create a plan on how to overcome these challenges.

The values demonstrated in Table 8.5 clearly show the negative impacts on industry 4.0 agenda implementation each challenge has on the organisation; it has been found that "Software and Hardware" represent the biggest issue among organisations. This is because the likelihood coefficient compared to other challenges identified is significantly larger. Organisations must integrate these technologies and invest in the hardware and software required to support industry 4.0 agenda implementation, this has been highlighted by literature by authors such as (Masood and Egger, 2019), who have highlighted the challenges users have encountered through interfaces between software. (Panettoa et al, 2019) have also highlighted interoperability as a key challenge organisations face when adopting digital advances which falls in line with the results gathered in this study, despite the identification of this challenge, authors have not assigned likelihood of the challenges being faced within organisation thus this study highlights that software and hardware software and hardware as the most likely challenge to be faced within organisations when adopting industry 4.0 strategies.

The second most impactful challenge is "Organisation Culture" which is essential to gain buy-in from senior members of staff which can accelerate the investment in the right software and hardware required. Authors such as (Nafchi and Mohelska 2020), (Mohelska and Sokolova 2018), and (Aguilar-Rodríguez, et al., 2021) have expressed that organisational culture is key to implement new processes in the business as the new processes need to be understood at an organisational level within industries.

"Resistance to Change" comes third as the most impactful challenge, this challenge has also been highlighted by authors such as (Reyes-Veras, et al., 2021) and (Hovarth and Szabo 2019) who have highlighted that employees tend to have difficulty adopting new processes as they view the new processes as changes in the way they are working. This study builds on these authors results as it highlights that resistance to change is the third most impactful challenge organisations face when implementing industry 4.0 strategies. The top three challenges that contain the higher likelihood coefficient impact each other as a domino effect.

"Knowledge and Understanding" challenge scores the same as "Competency and Capabilities" which are the challenges value closest to the best-case value as they both scored the same, this is because with all other challenges actioned and overcome, knowledge and understanding and competency of staff becomes less of a challenge. This has been supported by (Hofmann and Rusch,2017) and (Aripin, 2019) who have stressed that upon organisations having the right tools, software, and hardware, organisations can gain a wider understanding of these new processes. Additionally, if employees within organisations are not resisting the changes in these processed and the entire organisation has the same goals and vision in becoming more digital, the organisation as a whole can build on their knowledge and understanding of these new processes thus increasing their capabilities and competencies.

8.11. SUMMARY

This chapter discussed the barriers within the UK infrastructure sector when implementing Industry 4.0 agenda throughout the organisation. Six main challenges have been identified when it comes to the implementation of Industry 4.0 agenda in the UK infrastructure sector: (1) Software and hardware, (2) Knowledge and understanding, (3) Organisation Culture, (4) Resistance to change, (5) Competency and Capabilities, and (6) Funding and Investment barriers. In addition to this,

This chapter can be of great benefit to several audiences that are interested in the challenges of implementation of Industry 4.0 agenda as the success in implementing these strategies depend on the measure of the impact of these challenges. Implications have been documented as follows:

Theoretical implication

In this chapter, Industry 4.0 agenda implementation within the infrastructure sector has been explored, in addition, the challenges that block Industry 4.0 agenda implementation have been highlighted. There has been a limitation of literature on this topic regarding the infrastructure sector. The Graph Theory Matrix approach was utilised to quantify the challenges that were identified which acts as additional knowledge as it has not previously been explored. This will aid the decision makers to identify what action to undertake during their implementation processes to prepare and plan in accordance.

Policy implications

This chapter demonstrates an insight into the UK's infrastructure sector that is implementing Industry 4.0 agenda. Recognising the challenges in Industry 4.0 agenda implementation will allow higher management within organisations to adopt better decision-making when planning to implement technologies associated with Industry 4.0 agenda. Additionally, the presented challenge index calculated can allow organisations to review their status and ability to overcome the challenge based on their position at the time, this will allow higher management teams in organisations to identify the challenges that will mostly impact their implementation of industry 4.0 agenda and guide them to what appropriate strategy to undertake based on their resources and capabilities available. To conclude the six stages of change which have been introduced by Crosby in the 1980s were used to assess the following Six recommendations which have been drafted for both the Government and the industry to rethink and act upon (Sherri, 2012), the 6 C’s recommendations are:

1. Comprehension Policy: The UK Government should create and implement policies and frameworks for Industry 4.0 agenda which should be communicated in an understandable way to allow organisations within the sector a deep understanding of how to successfully implement Industry 4.0 agenda.
2. Commitment: Industry 4.0-based knowledge and capabilities are and will be in the future a huge challenge within the infrastructure sector as the more time goes the more technology is advancing, therefore Industry 4.0 agenda processes and standards training programmes related to the management of industry 4.0 agenda will allow higher management within organisations to change their mindset and gain a better understanding on how to successfully implement these processes.
3. Competence: The UK Government should develop knowledge-based strategies as it is of great importance to the developing an understanding of the fourth industrial revolution and the new processes introduced. This can allow the younger generation to gain knowledge on new ways of working and allow their culture to become solidified.
4. Culture: Organisations within the sector should change their attitudes towards a positive and open-to-learning approach to encourage better interaction throughout the organisation thus encouraging a successful implementation of Industry 4,0 agenda.

Industry 4.0 agenda should gradually be incorporated throughout the teams within the organisation from the management level including Human Resources, Administrators, Site Engineers, Commercial, Subcontractors, Agents, Planning team, Surveyors, Logistics, design, Stakeholders and Operations.

5. Capabilities: Businesses have adopted many Industry 4.0 agendas across the economy, to improve the infrastructure sector's position in the fourth industrial revolution, organisations need to consider their level of capabilities and competency for the fourth industrial revolution. Organisations need to avoid traditional practices and recruit more competent skilled staff who can also share knowledge with staff already within the organisation.

6. Collaborative Leadership: The development of digital and innovation strategies can be challenging and complicated as risks and issues, be they short-term or long-term, should be considered. These considerations should also include stakeholders to allow the collaboration of all parties. Consequently, a consistent approach throughout the senior leadership and management of the parties involved is a necessity for a successful implementation of Industry 4.0 agenda within the UK Infrastructure sector.

Upon taking the 6C's into consideration, it is also vital for organisations to ensure that they understand the progression of digital staff and employees. Digital staff within the sector tend to not have a path of progression due to the lack of understanding of the competencies and capabilities required to progress. Hence, organisations should ensure to have paths of progression for their digital staff as this can motivate staff members within this field in the sector to add more value towards their organisation and their careers.

CHAPTER 9: ANLYSIS OF INDUSTRY 4.0'S CONTRIBUTION TO UK INFRASTRUCTURE SECTOR

9.1. INTRODUCTION

This chapter describes the contribution achieved by organisations in the UK infrastructure sector due to the implementation of Industry 4.0 agenda. This chapter answers the ninth question:

"What are the efforts that Industry 4.0 agenda has contributed to organisations within the infrastructure sector?"

The results presented in this chapter are based on the qualitative data collected from 21 interviews from 5 large organisations and 8 small-to-medium organisations. the finding presented is based on the perspectives of the participants and supported by the literature.

Three main contributions were identified in this study were (1) Economic Values, (2) Social Values, and (3) Environmental Values, which are presented in Chapter 4, Section 4.6, Table 4.5.This chapter is split into two sections, the first section presents the thematic analysis which was conducted to underline the benefits and highlight the competitive advantages that have been found through implementing Industry 4.0 agenda within the UK infrastructure sector. The second section analyses the identified themes using the triple-bottom-line approach. The study outlines three main contributions which were divided into seven sub-contributions which have also been explored. The chapter then concludes with a summary of the results found and implications and future recommendations are outlined.

9.2. ECONOMIC VALUE

Abdul-Hamid et al (2020) and Khan et al (2021) investigate the impact Industry 4.0 agenda has on the organisations' economic competitiveness. The authors have identified that there is a relationship between the two Abdul Hamid et al (2020) argue that organisations adopting innovative technology along with digital and automated processes can witness an increase in economic profits which in term enables organisations to become increasingly sustainable economically (Abdul-Hamid, et al., 2020). The economic benefits of technology and the digital process has been an unclear aspect within the industry. On the other hand, Khan et al (2021) argue that Industry 4.0 agenda have a major aspect of impact on the organisations such as a positive impact on productivity and efficiency towards sustainability. Sustainability is a key aspect of Industry 4.0 agenda as it can allow a more integrated supply chain enabling access to real-time data about the whole construction process. This aids managers to keep track of production hence allowing decision-making to become more time-efficient and sustainable (Khan, et al., 2021).

The main contribution noted on the impact of Industry 4.0 agenda within the infrastructure sector has been highlighted as an increase in productivity and cost savings which improves the business performance of the organisation. In addition to this, organisations adopting innovative business models. Accordingly, organisations within the sector have witnessed contributions as such due to the implementation of Industry 4.0 agenda within their organisation, Interviewee PARE2 highlighted:

> *"On my previous project however we had a lot of pre-fabrication done which we benefit from doing the job by pocket rather than spending more costs."*

The interviewees' citation reveals that organisations within the infrastructure sector have witnessed a profit gain using prefabricated components of the asset for the project, cost savings were noted as the components were paid for before construction rather than the traditional way of ordering materials while on-site and constructing the components on site which would have made the construction process spending costs day to day for the materials and labour. Additionally, this has enhanced the productivity and efficiency of the organisation as time was reduced due to the prefabricated components. In line with interviewee PARE2, Yu et at (2021) noted that through Industry 4.0 agenda, organisations can benefit from the reduction of materials during construction. Additionally, the reduction of materials during construction can be a result of reusing materials and recycling which allows organisations to save costs and increase their efficiency benefits. Economic performance is a highly important factor for organisations in the infrastructure sector as maximising economic value helps companies increase their competitiveness within their sector (Yu, et al., 2021). Time savings and efficiency play an important role in improving an organisation's position within their sector as it positively impacts their financial position, for instance, Interviewee PARE1 states:

> *"The use of 4D and 5D has helped in terms of timing and cost management on my current project which has been amazing."*

As mentioned in Chapter 6, the Building Information Model has been the industry 4.0 strategy which has been mainly adopted by the participants' organisations due to the UK government mandate. Analysing the interviewee's statement reveals that the use of BIM in creating 4D and 5D models has helped the project in cost management. Their project combined the planning programme of the project with the 3D model to create multiples of 4D sequences which has aided in the visualisation of the planning programme, this enabled both the planners and site team to analyse the construction sequences proposed assisting in clash detection during construction and enabling the planning team to try different construction sequences choosing the more productive and efficient sequence. Savas et al (2015) argue that using industry 4.0 agenda such as Artificial Intelligence can allow organisations to save costs by integrating the automated processes within their teams. Savas et al developed an AI system to allow cost estimation with the use of data tools, this was incorporated with the planning programme, and it allowed for planning site operations enabling the savings of cost and time which are crucial in the infrastructure construction sector (Savas, et al., 2015), this demonstrates that organisations can gain contributions in terms of costs and time savings when implemented successfully.

Nascimento et al (2019) claim that Industry 4.0 agenda's impact on the economic aspect in general gains minimum attention as it tends to be neglected despite several studies suggesting that a new path to economic development contains the need to be explored in detail. Nascimento et al (2019) argue that there is a need for an economic model which can guide companies with the use of a framework. Economic benefits of a business align with Industry 4.0 agenda implementation as not only does Industry 4.0 agenda create an increase in production, but economic systems can also positively impact the growth in the world's population and the lack of resources within the sector (Nascimento, et al., 2019). Nascimento et al (2019) also argue that there is a need for a circular business model which can allow the integration of web technologies, in addition, this can enable organisations to understand how to recycle technology within their business while supporting the model. Draw inferences from your primary data analysis.

9.3.SOCIAL VALUE

In this study, increased innovation has been identified as one of the key drivers for organisations implementing Industry 4.0 agenda (See Chapter 5). As a result of this, organisations face demands to implement Industry 4.0 agenda as its importance means that the organisations become more innovative, this does not only contribute to more efficient and productive processes but also enables the organisation to increase their connectivity. Raicu and Raicu (2021) assert that for organisations to implement Industry 4.0 agenda, it is required for the organisation to increase their connectivity as it boosts communications, in addition, cyber threats need to be eliminated which pushes organisations to implement cyber security which is one of the many industry 4.0 agenda (Raicu and Raicu, 2021). Social factors are key aspects within the infrastructure sector, according to Yilmaz et al (2022) social impacts of Industry 4.0 agenda have been highlighted since 2016 the German Government who have introduced the Industry 4.0 vision, have highlighted that Industry 4.0 benefits producing social contributions which are focussed on the interaction between people and teams within an organisation and digital tools. Through the implementation of Industry 4.0 agenda, the development of this collaboration and communication is introduced within the supply chain regardless of time and location (Yilmaz, et al., 2022). Interviewee PARE15 explains how within their project, the organisation's social innovation has allowed the improvement of collaboration and communication during their operations and specifically during the start of Covid-19 in April 2020:

> *"[...] the viaduct had to have beam 18 lifted on the 28th of April, this was however very difficult as we did try to lift the beam, but something was catching it leading to it not being able to move. We tried everything and tried again the following week but no results. I was tasked to survey the Beam to incorporate it into the 3D model we must visualise what was stopping the beam from being lifted, however, I am classed as high risk and did not want to risk my health."*

It is evident from the statement of the interviewee that the infrastructure sector has found social contributions, especially during Covid-19. To explain the Interviewee's statement, work was delayed for 3 weeks as the organisation kept trying to lift the beam every week without any results, on the third week the beam was finally lifted. Due to the lockdown and participants being high risk, this has caused the project to be three weeks behind which costs a lot of money as staff members are still receiving salary without being able to do the required tasks. The senior engineer on this task also found it difficult to liaise with his team who were conducting the work as he was working from home, technological advanced such as video chat and meetings via online platforms have improved communications massively as without them work would be very difficult to carry on, however at the difficult time where the beam was proving difficult to lift, the senior engineer had no visual of what was going on as he could not go on-site or could not receive the surveyed coordinated from the surveyor to visualise it digitally via the 3D model. Satyro et al (2022) noted that Industry 4.0 can allow organisations to gain better social integrations, this can be achieved through implementing training strategies which can enhance the abilities of people within the organisation. This allows better relationships throughout the organisation (Satyro, et al., 2022), Nascimento et al (2018) argue that Industry 4.0 agenda implementation introduces changes to the work environment which changes ways of communication and sustainable value chain, this is mainly due to creation, communication and collaboration streams which are currently employed in organisations within the infrastructure sector will see a shift where these social avenues will become digital.

An example of this is presented by Organisation E where on one of their projects, an Artificial Intelligence data System was implemented for one of their tasks. Organisation E focused on improving safety with the use of AI data. The project aimed to obtain advanced planning to eliminate safety hazards throughout the asset maintenance phase as this was a tunnelling project. The system that was developed was made to detect safety hazards through photos and other project data producing an unbiased and automated risk assessment for the team members to gain an outlook different to their perspective on the hazard in place. The observation product that was developed worked by combining mobile apps where one scored the hazards and the other contained the safety data of the company, this would then rank the safety hazard and alert the teams.

Organisation D who has also implemented AI on one of their projects highlighted the use of AI impacting risk management. Organisation D created an AI system for the analysis of risk data, the project teams would gather risk data to enable them to manage risks within their project. The project team used AI to gain more risk data and allow them to predict the issue before it happened. The AI engine was introduced and was made to use data from the smart engine where previous data was collected and stored to help rank and predict risk factors. Human-based observations were also implemented to have both perspectives and choose which factor was to be more focused on. The AI system would analyse images from the project data which were previously gathered within the construction management systems then identify the key risk indicators. In this case, this saved a lot of time as if this was tasked to a human, the review of all these photos would be impossible.

Organisation E and Organisation D, however, have expressed that these Industry 4.0 agendas are only implemented on one of each organisation's projects. Both projects are similar in that they are undertaking maintenance works hence these systems are not implemented across the organisation. This however has created a good relationship with the clients as operations are being conducted through automated processes, clients can also review their assets through the AI stream as the system contains stored data and imagery of the physical conditions of the asset where people do not need to physically observe the asset to view its status. Using automated processes allowed the clients to gain a good relationship with the organisations where efficient process is being used for inspections. This agrees with Nena et al (2021) assertation that using automated inspection processes for housing owners (clients in the case of the study) results in a growth in social benefits.

9.4.ENVIRONMENTAL VALUE

The infrastructure sector plays a massive role in the environment as creating more environmentally friendly infrastructure and incorporating environmentally friendly processes through construction can massively impact emissions. Additionally, the infrastructure sector partakes a major role in the UK Government's Net Zero strategy which is aimed to be accomplished by 2050 (HM Government, 2021). Within the infrastructure sector, sustainability is becoming more of a key factor during the process of decision-making while considering the whole lifecycle of the asset as the construction industry has a massive impact on our environment due to the use of raw material, energy consumption and C02 emissions (Eldik, et al., 2020). In this study, interviewees have stressed the need for their organisations to use methods and processes for their activities with minimal environmental impact.

Henke et al (2020) argue that the infrastructure sector has found it difficult to gain sustainable processes as within the sector, there are processes within the process of constructing infrastructure assets where goods are to be moved daily and people which impacts the environment due to emissions and in turn impacting the quality of life (Henke, et al., 2020). Salehi et al (2021) assert that organisations within the sector created masses amounts of waste during construction which can be reused or recycled as a sustainable strategy to in turn reduce the negative impact the sector has on the environmental performance. The interviewees have provided statements which prove there is an agreement that the UK infrastructure sector needs an improvement in environmental performance and their organisations have taken steps to achieve such. Environmental values highlighted were reduction of CO2 emissions, reduction of energy consumption and reduction of waste. Interviewee PARE9's statement elaborates on their organisation's commitment to reduce CO2 emissions within one of their projects:

> *"[…] we were tasked by the client during the tender stage to reduce CO2 emission by at least 15% during the initial stages of the project before the start of construction. We took the initiative to combine technology and data to incorporate our 5D+ tool to calculate CO2 emissions during tender […]"*

The analysis of Interviewee PARE9's statement highlights that 5D was implemented in one of the organisation's projects that took part in this study, this 5D included a CO2 emissions calculation tool which allowed the team to calculate CO2 emissions of the project, the tool enabled CO2 values to be added to each element and material supporting the calculation of the emission. This was a breakthrough as it was conducted during the tender stage allowing early calculation before the start of the project and with this information, the organisation could choose different materials to cut CO2 costs.

Organisation A gained early involvement with the project which allowed the contractors to introduce new ideas and get involved early, leading to new tools being used to increase efficiency from the pre-construction stage. This project has implemented many digital tools from the start including the Building Information Model and a 5D plus tool. In addition to calculating CO2 emissions, the tool also calculated cost estimates. With these digital tools, the project has highlighted a total savings of over £2 million by incorporating the benefits of the tool within their main works. Not only were cost savings noted, but also time reduction was calculated and with the tool automating manual calculations, this led to a reduction in the required staff to conduct the task. Salehi et al (2021)'s study contained similar results where carbon fibres being used within industries for purposes such as the production of vehicles deemed as a process which required a mass amount of energy consumption. In addition to lignin, carbon fibres have multiple uses where they can be used for infrastructure where they will be used for reinforced roads. Salehi et al have proposed the use of lignin-based fibres which has been proven to reduce energy consumption compared to conventional carbon fibre by about 5% as the material can be recycled (Salehi, et al., 2021).

The UK Infrastructure sector is aware of the importance of reusing materials on-site and reducing waste as a goal as it aligns with the UK Governments Net Zero Emission Strategy. The construction sector including buildings and infrastructure is the largest consumer of materials currently in the UK, especially during the construction stage of the asset. Magalhães et al (2017) asserted that for the construction infrastructure sector to gain better waste management and in turn reduce waste created, the strategies of the highest importance that are required is to have a fully integrated project team where communication flows especially during the design stages. Furthermore, a detailed design of the elements within the asset is required to be coordinated and used to its advantage (Magalhães, et al., 2017). The process and technology available through Industry 4.0 agenda can aid in allowing the strategies proposed by Magalhães et al (2017) to become achievable.

9.5.DISCUSSION

The UK's infrastructure sector has been noted to be one of the main sectors that could highly benefit from Industry 4.0 agenda through digitisation and automation, the benefits which are of high value within the sector equal amongst economic, social, and environmental this chapter studies the highlighted the values and provides an analysis of the created values from the organisations of industry 4.0 agenda using the Triple Bottom Line (TBL) approach. Organisations previously mainly focussed on environmental and economic aspects for performance, however, Tate and Bals (2018) have noted that social concerns have become a main aspect which is considered key for organisations to consider (Tate and Bals, 2018). Therefore, organisations within the infrastructure sector need to focus on these three dimensions to enhance their performance which allows more work winning and an increase in profit. Accordingly, the organisations within the infrastructure sector that have implemented Industry 4.0 agenda have noted the values that the implementation has produced for their organisation. They have gained value through gaining an increase in productivity, improving their reputation within the sector and achieving a reduction in environmental impact, therefore, improving organisations' profits, for example, organisations in the infrastructure sector have better relationships with their stakeholders, reducing CO_2 emissions and ensuring their staff's wellbeing is taken care off results in an addition of value to the stakeholders, which in this case is users of the assets which are consumers of the assets, this increases the overall performance of the organisation improving its reputation and increasing profit. This is why organisations should implement an Industry 4.0 agenda as the value gained are long-term with a definite return on investment (Chen, 2021). This chapter's findings demonstrate that the Economic, Social and Environmental initiatives are interconnected in impacting the organisation's performance. These findings are supported by Nascimento et al. (2019), Nena et al (2021), and Magalhães et al (2017) who have asserted that Industry 4.0 agenda creates value for organisations within the infrastructure sector. The infrastructure sector can achieve an increase in productivity while using efficient methods which improve organisations' reputations and increase their competitive advantage within the sector, allowing them to enter the fourth industrial revolution and integrate into more markets within the sector. Eslami et al (2020) agree and assert that improving the production rate with the customisation and better delivery processes can positively impact organisations financial performance (Eslami, et al., 2021). Yu et al (2021) have emphasised the importance of organisations gaining a competitive edge within their sector as this enable organisations to become more respected and win more work increasing economic performance. Organisations within the sector are starting to incorporate digitisation and automation into their higher-level strategies, this shows that the sector is aware of the values that can be gained through implementation. Most infrastructure projects are funded by the UK government; thus, implementation of Industry 4.0 improves the relationships between the government and organisations. In addition, infrastructure assets are used by communities, hence organisations can also benefit from improving their relationship with the community creating better stakeholder interaction. Fragapane et al (2022) agree with the results finding as they have affirmed that Industry 4.0 agenda allows better productivity within the manufacturing sector. This is because the introductions of automation and prefabricated materials save time when compared to traditional practices of constructing assets on site. This allows the materials to be placed on site already constructed leading to a more productive construction process. In addition to this, waste products can be reduced as the prefabricated elements required can be ordered to specific amounts required which in line reduces costs as the exact quantities needed can be purchased saving extra materials purchase (Fragapane, et al., 2022). Digitisations of assets and automation can also aid in waste reduction as with available data and 3D models, organisations can calculate the exact quantities they need via a reflective digital twin of the physical asset ensuring accuracy will allow the purchasing of the exact quantities required. Even though the implementation of Industry 4.0 agenda provides long term economic benefits, the initial cost of implementation can be high, however, the end return on investment can help organisations to gain a higher company revenue and reduce costs overall with environmental and social benefits to be gained. The relationships between the identified value of implementing Industry 4.0 agenda are demonstrated in Figure 9.1.

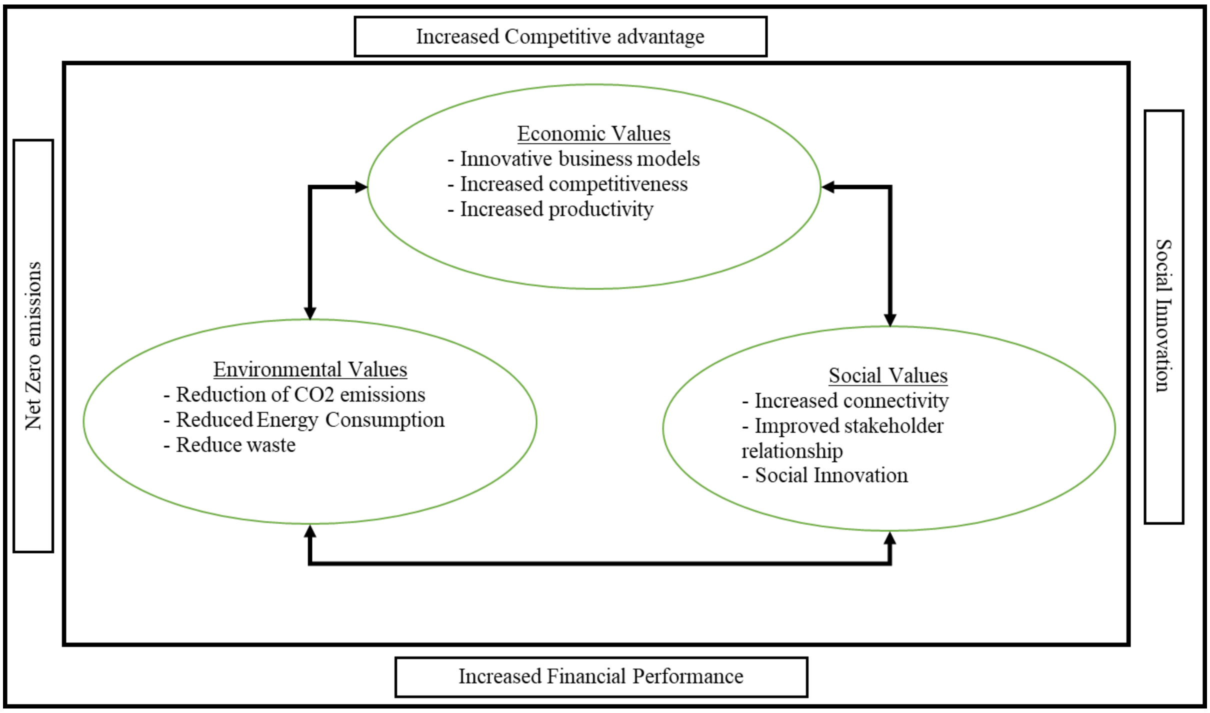


Figure 0.1: The impact of Industry 4.0 agenda implementation within the UK infrastructure sector.

9.6.SUMMARY

This chapter discusses the value that implementation of Industry 4.0 adds to organisations within the UK infrastructure sector, these values have been analysed using the Triple Bottom Line approach.

- **Theoretical implications**

This chapter studies the value of industry 4.0 agenda implementation gives to the UK Infrastructure sector using the Triple Bottom Line approach. This context concerning the construction infrastructure sector have never been explored before, the finding presented in this chapter can provide support to researchers in connecting the links between Industry 4.0 agenda and the economic, environmental, and social performances of an organisation. This required a more in-depth assessment concerning the context of this study.

- **Managerial implications**

This chapter presents suggestions through the values that will impact higher management within organisations in the UK infrastructure sector. The chapter demonstrates the relationships between the implementation of Industry 4.0 agenda and the performance of the organisation. This is of importance to higher management as this allows an increase in knowledge of Industry 4.0 agenda and allows the understanding of how Industry 4.0 agenda positively impact social, environmental, and economic values. This knowledge can allow the higher management within organisations to understand the advantage of Industry 4.0 agenda and in turn plan on how to successfully adopt these strategies to their advantage.

- **Policymakers**

This chapter offers an insight into the positive impact that Industry 4.0 agenda has had within the UK infrastructure sector. As one of the largest sectors in the UK, the finding of this chapter can be found useful to policymakers allowing the understanding of the importance of the fourth industrial revolution and developing industry 4.0 agenda standards and guidance that will align with future economic goals such as the Net Zero Strategy, hence, the following recommendations could be of use to different parties:

- ***Organisations***: organisations within the infrastructure sector should ensure that industry 4.0 knowledge is shared throughout the organisation allowing enhance collaboration and knowledge sharing through all parties.
- ***Higher management***: Higher management within organisations should integrate and incorporate industry 4.0 agenda and technologies within their processes and gain a competitive advantage, this will require the upskilling of staff, however over time this will generate a positive impact on processes and efficiency.

CHAPTER 10: INTEGRATED BUSINESS MODEL FRAMEWORK AND READINESS TOOL FOR IMPLEMENTATION OF INDUSTRY 4.0 STRATEGIES IN THE UK INFRASTRUCTURE SECTOR

10.1. INTRODUCTION

In this chapter, the integrated business model framework and industry 4.0 readiness tools to be used for the implementation of industry 4,0 strategies in the UK infrastructure sector are detailed. This answers the final research question:

"Is there a need for developing an innovative business model for adopting Industry 4.0 agenda within the infrastructure sector?"

The Industry 4.0 readiness tool and business model framework was developed with the use of the findings collated from the previous chapters. This chapter is presented in two sections. In the first section, the business model framework is explored, following this, the second section details the development of the Industry 4.0 readiness tool. The triple bottom line approach introduced by Elkington where the environmental, social, and economic dimensions are demonstrated for the framework to understand the wider functionality. The final business model framework proposed is aimed to aid organisations during the implementation of Industry 4.0 strategies with their situation taken into consideration. The industry 4.0 readiness tool developed is based on the following perspectives:

1. Change in process.
2. The content of change
3. Context of organisations
4. Attributes

This tool can be useful for organisations within the sector to assess their ability to adopt Industry 4.0 strategies and highlight any aspects on which they can improve to guarantee successful implementation.

10.2. RATIONALE OF INTEGRATED BUSINESS MODEL FRAMEWORK FOR IMPLEMENTATION OF INDUSTRY 4.0 STRATEGIES WITHIN UK INFRASTRUCTURE SECTOR

Within an organisation, change is to be analysed at a deeper level as it not only affects the higher management, but all parties involved will need to understand the changes that are occurring to achieve an efficient change in processes (Jallow, et al., 2022). Akbar et al (2019) argue that for organisations to efficiently manage change, coordination and communication must be managed throughout the organisation (Akbar, et al., 2019). This study highlights the importance and need for Industry 4.0 initiatives in conjunction with the benefits that can be gained creating value and productivity within the UK infrastructure sector. Hence there is a high importance for the development of a business model framework within the infrastructure sector organisations which can assist in a better understanding from higher management in recognizing Industry 4.0 drivers and challenges, in addition to this, the value of Industry 4.0 strategies can be identified and clearer within organisations. Gajdzik et al (2021) have stressed the importance and need for a structured framework for Industry 4.0 implementation as there is a lack of a general framework available for Industry 4.0 implementation (Gajdzik, et al., 2021). The authors stress that the global environment has evolved as there are newly developed innovations and processes which require a standardised framework for parties within organisations to adopt Industry 4.0 strategies.

10.3. UNDERSTANDING INDUSTRY 4.0

Organisations within the infrastructure sector are currently receiving high pressure from stakeholders to implement industry 4.0 strategies where higher management seeks to address the impacts of their current processes environmentally, socially, and economically. This has led to technical terms such as Artificial Intelligence, Virtual Reality, Big Data and Cloud computing being used frequently within the infrastructure sector despite the technologies being implemented. These terms and technologies are being used, however, there is a major lack of understanding of the term "Industry 4.0" itself which is affecting the sector in the understanding of the urgency of entering the fourth industrial revolution, in addition to this, globally Industry 5.0 is currently at its prime where the infrastructure sector has not fully grasped Industry 4.0 and are yet to advance to Industry 5.0. Mhlanga (2021) argues that the gap with Industry 4.0 within the sector is to do with understanding the nature of the intelligence that can be used with these technologies, systems, and devices to improve processes (Mhlanga, 2021). Hence organisations need to first understand the challenges currently being faced within the sector in terms of social, environmental, and economic to gain an understanding of how Industry 4.0 initiatives can be implemented to tackle these challenges.

In addition, industry 4.0 technologies are becoming a key aspect within the industry as the world is turning digital (Sanders, et al., 2016). This study integrates the views of Industry 4.0 from organisations within the sector, it has been noted that the implementation of Industry 4.0 strategies is influenced by a variety of factors such as government laws and competitiveness (see Chapter 5). Gaining a deeper understanding of these influential factors can assist higher management in the development of the most effective industry 4.0 strategy depending on their key drivers. This enables higher management to predict the changes to be made within the organisation based on the drivers and their requirements allowing innovation to be enhanced and clear across the organisation and parties involved.

10.4. NEED FOR INTEGRATED BUSINESS MODEL FRAMEWORK

The infrastructure sector consists of complex activities and involves a wide supply chain where tasks can tend to be of a high level of complication. Due to this, industry 4.0 strategy implementation can benefit the different tasks and activities involved within the sector. Khattak et al (2016) argue that infrastructure projects are becoming more complex due to an increase in stakeholders and a variety of perspectives and ideas amongst the different stakeholders which generates uncertainties, especially within the project management competencies (Khattak, et al., 2016). Consequently, the development of a business model framework can highlight the requirements for a successful implementation of industry 4.0 strategies, in addition to highlighting the requirements, the generation of a business model framework also highlights the value, revenue and channels required for a successful implementation. Additionally, Golan et al (2020) argue that in terms of Industry 4.0, there is a necessity for a framework to be developed as Industry 4.0 strategies require machine and human interaction, the development of a framework is necessary to define that interaction allowing a more productive environment while there will be the availability of a classified interaction (Golan, et al., 2020). The authors added that Industry 4.0 introduces new improved abilities which require a framework to create support in implementing the changes that come with Industry 4.0 strategies.

As defined by Oghazi et al (2022), a framework is a tool that aids in identifying the aspects that are vital for a phenomenon to be understood, this is vital as the linkages and interrelationships can be highlighted between the various aspects (Oghazi, et al., 2022). The capability of identifying the linkages between the factors allows higher management to improve decision-making as it highlights the key aspects that may require more consideration and if they need to be developed further. Literature has highlighted there is a lack of framework within the infrastructure sector in terms of Industry 4.0, there is a gap between theoretical and practical literature on this subject. Golan et al (2020) argue that there is a lack of research and standards for an Industry 4.0 strategy framework which is vital for achieving Industry 4.0 within the infrastructure sector. In this study, a question was raised during the face-to-face interviews held digitally to gain knowledge of whether industry experts within the organisations that took part in this study think that the business model framework would assist the adoption and implementation process of industry 4.0 strategies. There was a unanimous agreement that the sector would find it beneficial that a structured innovative business model framework would be useful in the implementation of Industry 4.0 strategies within their organisations. For example, PARE2 states:

> *"Yes, I think if we have got guidance to do something properly it will be massively beneficial to not just my organisation but the entire industry. Getting evidence of how it will work and going to be used can provide good business cases for organisations to follow."*

According to PARE 2, there is a need for business model frameworks, and they highlight the benefits of a framework. In line with PARE 2, Interviewee PARE5 cites:

> *"Yes, definitely currently we are having to cope with different challenges every day, if we had a standard guideline, it would be simpler so I would say it needs developing to reduce the challenges we are facing today."*

Based on this study and the responses from the interviewees, it is clear that there are frameworks that have already been implemented towards industry 4.0 strategies such as BIM, however, it should be noted that the current frameworks implemented do not take into account all industry 4.0 strategies, therefore it would be greatly beneficial for the sector to obtain an integrated framework which incorporates each organisations vision towards industry 4.0 strategies which includes the economic, social and environmental benefits.

Overall, from the analysis of the responses collected from 21 participants and the review of the literature, it is apparent that there is a necessity for the development of an integrated business model framework for the transformational changes and successful implementation of Industry 4.0 strategies within the UK infrastructure sector.

10.5. BUSINESS MODEL FRAMEWORK BENEFICIARIES

The business model framework proposed is aimed to benefit organisations in the infrastructure sector within their processes and procedures. It is also intended to assist organisations in establishing industry 4.0 strategies aiming to become more innovative and achieve better performance. The business model framework is created to enable higher management within the sector to improve their decision-making where concepts of Industry 4.0 can be better understood. In addition, the implementation process and change management strategies can be better understood where success can be measured. The creation of an in-depth business model framework allows the organisations to better understand the following aspects:

- The drivers for Industry 4.0.
- The linkages amongst the key factors and processes to be undertaken to fully adopt Industry 4.0.
- Industry 4.0 strategies impact the organisation's performance and innovation.
- Influence on organisation's competitiveness.

Generally, a business model framework allows the organisations within the sector and stakeholders to better understand the fourth industrial revolution across the supply chain, this enables potential challenges to be identified and where industry 4.0 can be better implemented.

10.6. PROPOSED INTEGRATED BUSINESS MODEL FRAMEWORK FOR THE IMPLEMENTATION OF INDUSTRY 4,0 STRATEGIES IN THE UK INFRASTRUCTURE SECTOR

The proposed framework is presented in Figure 10.1 which was designed using the findings from both the literature reviewed and the analysed data from the interviews conducted with experts within the UK infrastructure sector and discussed in the following sections below. The framework is made up of four stages which are: inputs, processes, outputs, and results. A systematic approach was adopted for the framework which combines a variety of frameworks and models such as Osterwalder's Business Model Canvas (2010) and Gassmann's Business Model Navigator. The information inputs combine the internal and external pressures from organisations that influence the decision-making process, encouraging the adoption of Industry 4.0 strategies. Upon evaluation, the inputs can allow higher management to understand the right industry 4.0 strategies that they can implement and integrate into their processes. This can happen through the change of their structure, culture or systems which cover the dimensions of the TBL where the initiatives adopted impact those dimensions. The digital and innovation leads of the organisation result in increasing innovative performance which has been split into groups namely economic, social, and environmental performances which heavily impact the future performance of the organisation. The framework contains a continual feedback loop to guarantee the information being generated is connected to the actual performance of the organisations and allows the decision-makers within the organisation to modify their Industry 4.0 strategies for future adoption and implementation.

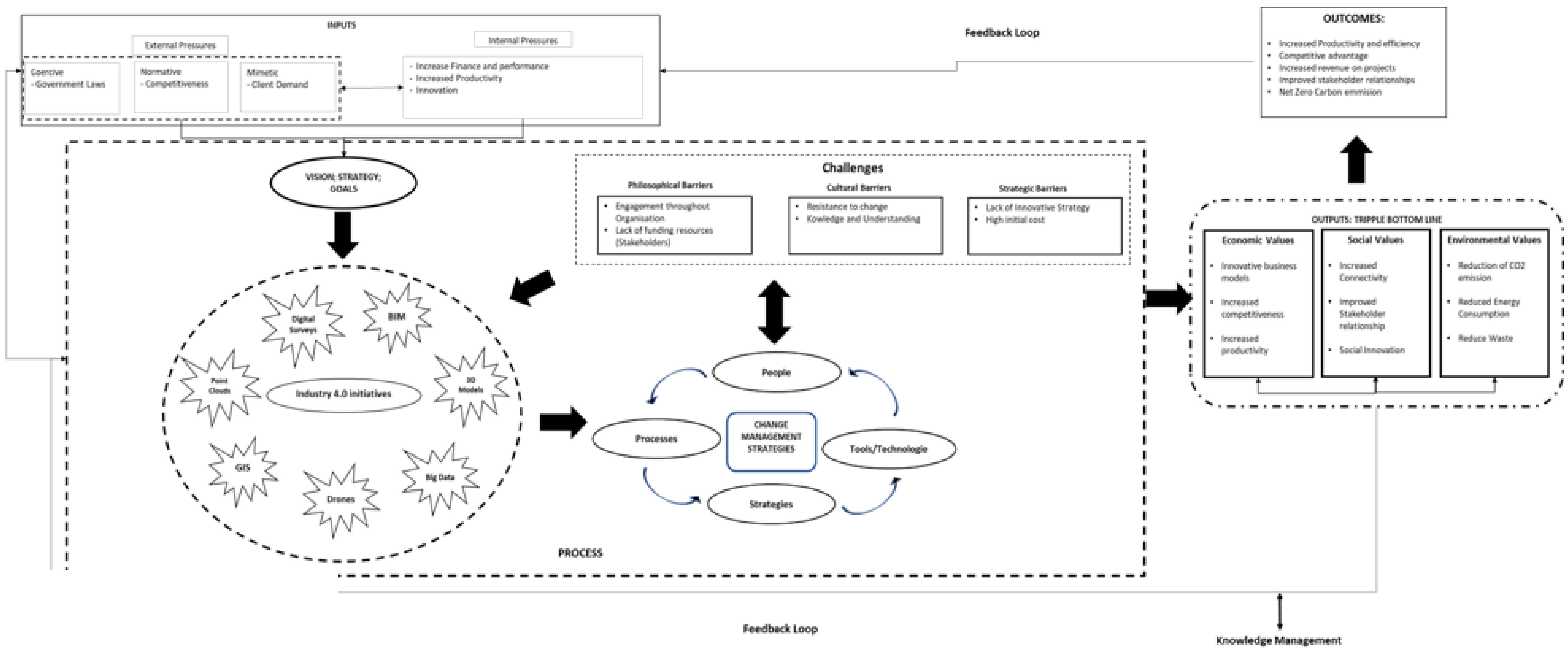
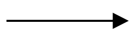
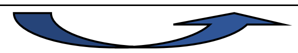
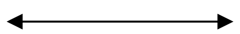


Figure 0.1: Proposed Integrated Business Model Framework for the implementation of Industry 4.0 initiatives in the UK infrastructure sector.

Table 0.1: Arrows Link representation

Arrow Style Link	Link Representation
	Processes links in framework
	Link of Stages preset in framework
	Loop of Changes to feed into each change process
	Two-way continuous feedback between actions

INPUTS

The proposed framework inputs are represented by the key drivers identified for the implementation of Industry 4.0 strategies in the UK infrastructure sector. The key drivers are vital in organizing the levels of implementation of Industry 4.0 strategies within organisations. The identified inputs were divided into two groups where one derives from perspective theory and the other was resource-based. The *External drivers* included pressures from certain forces such as client demand, government laws and competitiveness. The *Internal Drivers* include forces such as increased finance and performance, innovation, and increased productivity. These key drivers encourage organisations to assess their business processes, Innovative status and capabilities which is why it is crucial for organisations to fully understand the key drivers as they positively impact the implementation success rate. Understanding the key drivers allows organisations to understand the internal capabilities that are required for successful implementation to fulfil the external and internal drivers. A relationship between the key drivers was recognized for this framework and Figure 10.2 demonstrates the relationships between the key drivers and these are further expanded on in Figure 5.2. Six key drivers were identified as factors that encourage the UN infrastructure sector to implement industry 4.0 initiatives. The external drivers were grouped into the pressure types that they employ in the organisation. These groups are:

- ***Government laws:*** Coercive pressure from the government has a massive influence in setting social and innovative standards that organisations must implement as necessary to avert penalties.
- ***Competitiveness:*** Normative forces are characterized by their power to create pressure on implementing industry 4.0 initiatives as a necessity before an agreement of business with them.
- ***Client demand:*** The mimetic pressure pushes organisations to gain effective engagement and interaction with Industry 4.0.

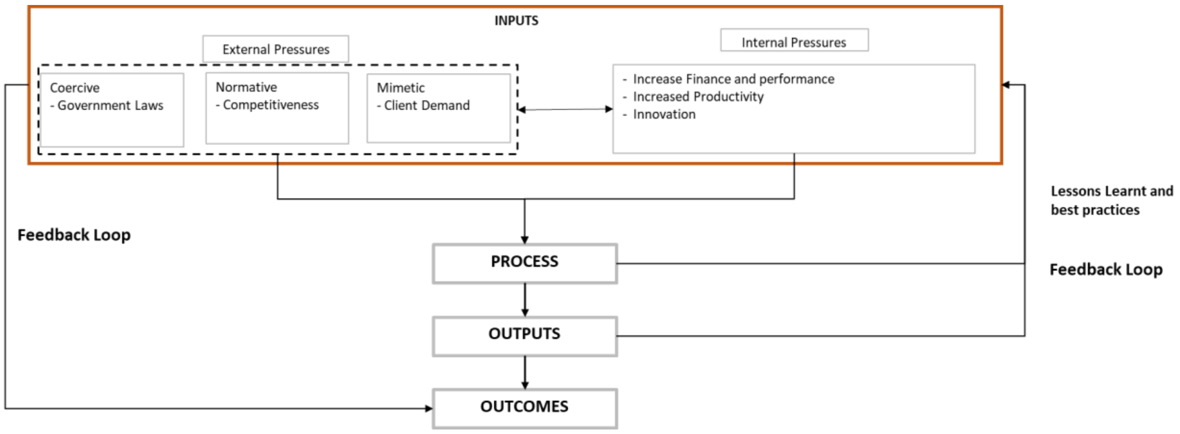


Figure 0.2: Inputs section from the proposed framework

The internal drivers that were identified relate to the capabilities and available resources of the organisation that drive the implementation of Industry 4.0 initiatives.

- ***Increased finance and performance:*** Increased finance and performance encourage organisations to implement industry 4.0 initiatives as it impacts competitiveness within the competitive market.
- ***Increased productivity:*** Providing added skills and capabilities to employees through training, the advancement of employees pushes organisations to pro innovative and sustainable strategies while improving the workforce.
- ***Innovation:*** Innovative and industry 4.0-minded leaders within the organisation are classed as a driver as they can influence achieving the necessary resources and capabilities to implement industry 4.0 strategies.

A multidimensional conceptualisation was conducted of both internal and external drivers as inputs, this included the drivers that are connected. This is necessary for organisations as it enables positive influence on them for the implementation of industry 4.0 initiatives. Organisations within the sector have different visions and drivers which would impact the strategy adopted. The TISM was used along with Fuzzy MICMAC analysis to distinguish the relationships between the key drivers (see Chapter 5 for more details). Furthermore, the useful areas were split into two areas to improve the practicality of the framework. These are the two key actions:

- ***Increase validity:*** This is the review of the additional external pressures and requirements from stakeholders such as the client, government, and competitors. These have been the main factor of influence within the sector for industry 4.0 initiatives implementation. For example, the client may demand a certain process or task that requires automation, and organisations that do not meet the requirement receive a competitive disadvantage compared to those that do, which is why it is vital to building on capabilities throughout the sector.

- ***Enhancing capabilities***: This is an assessment of the resources available and the business processes of an organisation that encourage the implementation of industry 4.0 strategies. For example, increased productivity is an input that is important for organisations wishing to implement industry 4.0 strategies as relies on engagement between them.

PROCESS

Once the inputs were analysed carefully, the business demands from an external point of view was assessed in conjunction with the available resources and capabilities that the organisation contains. This allows higher management within the organisation to develop procedures and processes suited to the implementation of industry 4.0 initiatives allowing for successful implementation. Following the inputs, the processes stage is the next stage within the proposed framework which includes parts which are as follows:

- The organisation's vision, strategies, and goals.
- The industry 4.0 initiatives.
- The change management strategies
- Challenges of implementing industry 4.0 Initiatives These four parts were split into further four subprocesses which are:
  - The interpretation of Industry 4.0 strategies.
  - Implementation of Industry 4.0 initiatives
  - The management of change to address Industry 4.0 initiatives
  - Classification of the challenges creating a barrier for Industry 4.0 initiatives.

The main areas of the processes within the framework are demonstrated in Figure 10.3:

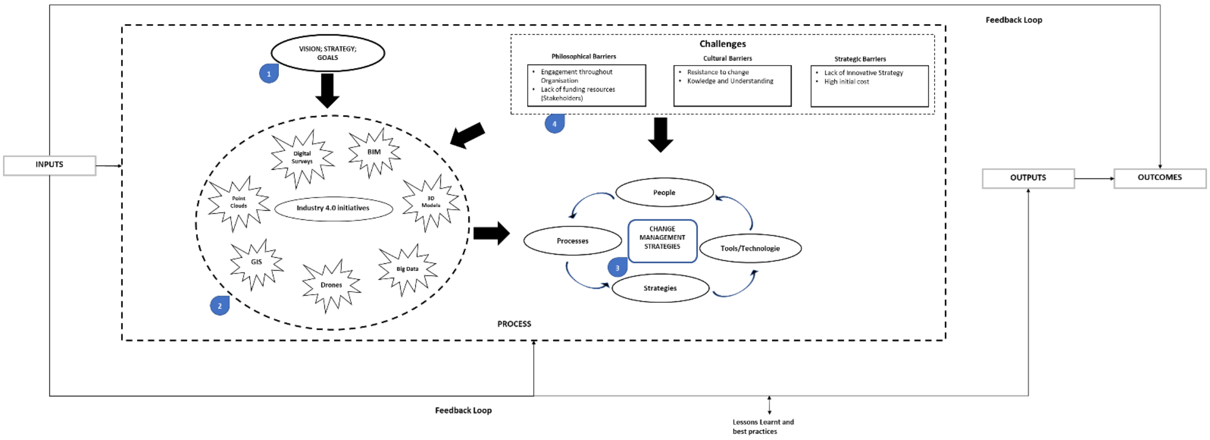


Figure 0.3: Process partition of the proposed framework

- ***Vision, strategy, and goals***: An organisation's strategic vision is an essential part of the organisation's development (Slåtten, et al., 2021) as it highlights the core purpose and values of an organisation and what their end goals are. Industry 4.0 is an end goal for organisations will mean that they should include objectives that are in line with the visions classification to allow successful implementation (Sarros, et al., 2011). The strategies for the organisations are represented by guides and standards that they need to adhere to achieve the vision and goals set.
- ***Industry 4.0 initiatives***: Organisations have taken actions such as introducing innovative processes and industry 4.0 technologies where they intend to achieve their industry 4.0 visions and goals. For example, these initiatives include the adoption of BIM where employees in the organisation are being upskilled and trained on the new processes (see Chapter 6 for more details).
- ***Change management strategies:*** The introduction of new and complex processes creates new challenges to overcome which require organisations to address the necessary changes for successful implementation. This is why change management is crucial to adjust to the new processes, this is not limited to leadership changes, structure, organisational culture, systems, and technology which are all essential for a successful implementation of industry 4.0 initiatives (see Chapter 7 for more details).
- ***Industry 4.0 implementation challenges:*** These are barriers that organisations face through the process of implementing Industry 4.90 initiatives. For example, software and hardware challenges, lack of knowledge and understanding, and lack of funding (see Chapter 8 for more details)

Within the proposed framework, some sub-processes make up the processes stage which acts as a tool guiding the decision-makers within organisations to delve into the required processes when implementing industry 4.0 initiatives. The processes stage demonstrates the linkages of the different sub-processes making it not linear, this can be associated with the garbage-can model for decision making where different aspects of the process can be taking effect instantaneously. Key actions within this stage are defined as follows:

- ***Create industry 4.0 strategies:*** within the sub-processes, there are two key steps which are ***the input integration*** **and** ***development of strategies.*** The processes begin with the integration of both internal and external drivers which form the inputs of the framework, this enables organisations to set their industry 4.0 vision and goals. Within this step, the higher management within the organisation and the decisionmakers can recognize what resources, capabilities and responsibilities are required for the fourth industrial revolution. The proposed Industry 4.0 maturity model presented in Chapter 6 can be used as a tool for the assessment of organisations within the infrastructure sector's current state concerning Industry 4.0 (see Chapter 6 for more details). Assessing organisations' status in the fourth industrial revolution enables them to identify the right industry 4.0 initiatives which can address certain situations and processes in the organisation. This is a crucial stage within a strategy implementation process as organisations can recognise their strategic limits and what can operate with these boundaries. Following the integration of the inputs, the development of the strategies commences which is where organisations transform their vision into strategies to achieve their goals in terms of industry 4.0 strategies with the relevant resources and capabilities. During this step, it is vital to include the stakeholders as they are a key part of developing the strategies, stakeholders such as clients, suppliers, community, and the entire supply chain are to be included (Robinson, et al., 2006).
- ***Implementation of the Industry 4.0 initiatives:*** During the adoption of Industry 4.0 initiatives which is highlighted in the sub-processes, the organisation's tasks and procedures are outlined. The TBL was used to categorise the industry 4.0 initiatives which are BIM, GIS, 3D Models, Drones, point clouds and Digital Surveys, and Big Data (See Chapter 6 for more detail). These Industry 4.0 initiatives have been classified into six groups and then further divided into levels, namely strategic, tactical, and operational (Zidane, et al., 2016). The strategic initiatives are those that higher management is to fulfil, for example leading and establishing the vision, whereas both the tactical and

operational initiatives are derived from the strategic initiatives. Tactical initiatives are managed by the mid-level management within the organisation who are more involved in the planning stages and design stages of the tasks. During the operational level, the site activities are involved where the supervisor/supply chain level within management gets involved where they oversee delivering the project and reporting progress and construction activities with the use of industry 4.0 initiatives. For example, if an organisation aims to adopt Drones as an Industry 4.0 initiative, the goal of the initiative and aims for use will be described within the strategic level with higher management. During the tactical level, midmanagement can start planning on how to execute the use of drones to enhance productivity and efficiency for example progress monitoring which leads to the operational level where the drones will be used to conduct these planned tasks by the operational team and they operational level supervisors and supply chain. Figure 10.4 demonstrates the levels within the organisation and the decision-making and management.

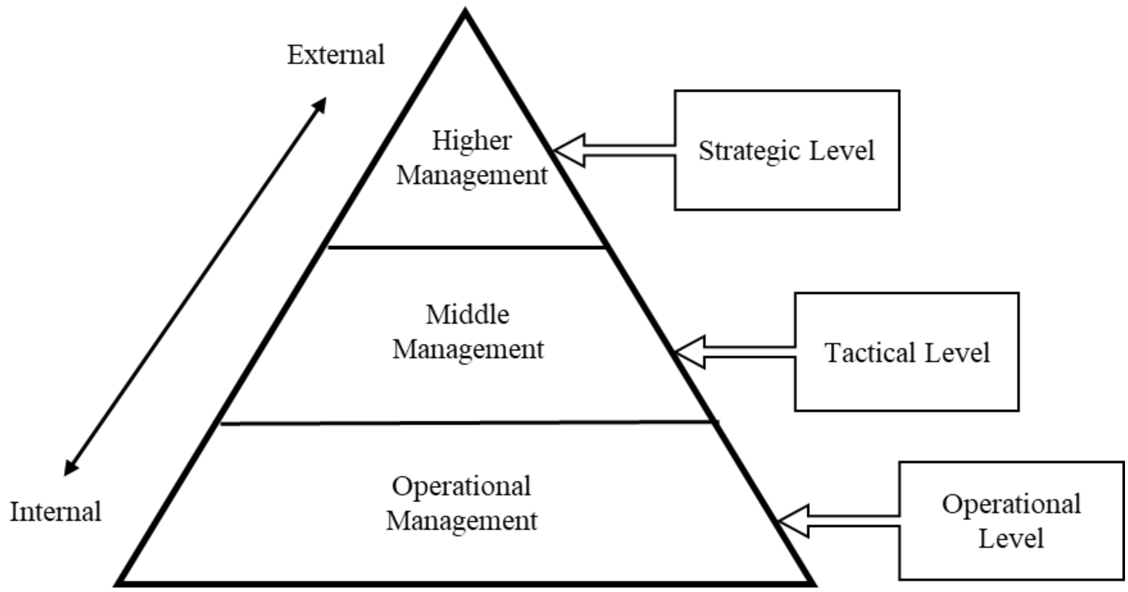


Figure 0.4: Decision-making levels of an organisation.

To further explore these levels, Figure 10.5 demonstrates an example of an Industry 4.0 initiative, namely Drones and the connection to the level of management within the organisations including the TBL analysis, organisations should however note that these initiatives are to be recorded as it benefits them to be able to quantify and qualify the usefulness, an example of this can be found in Chapter 9.

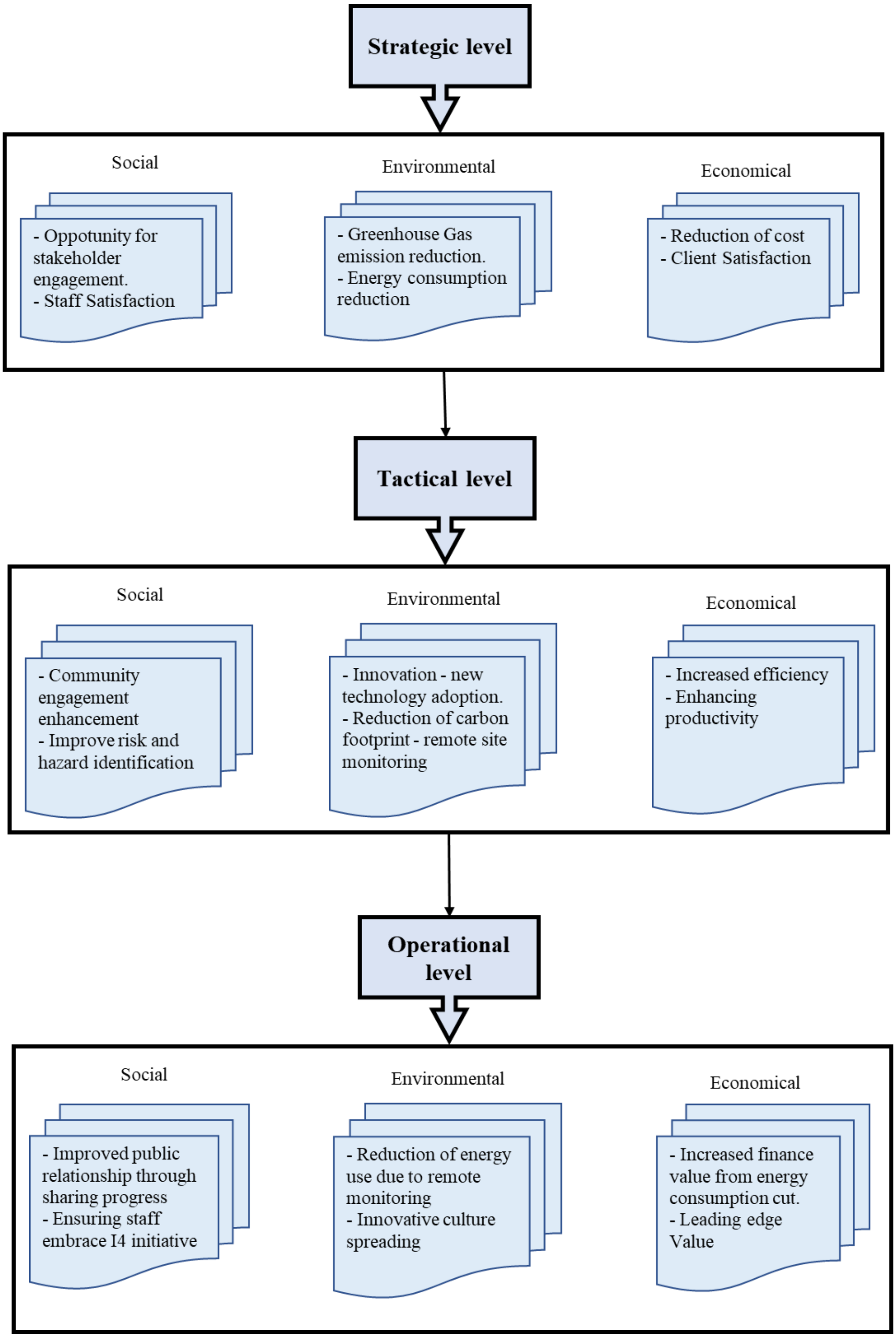


Figure 0.5: Example of Industry 4.0 initiative Drones adoption decision-making process across

- ***Integration of change management strategies:*** Organisational change management is a key aspect of new processes being adopted. This is because the organisations' structure, culture and systems are to be altered to tie in with the introduction of change especially with industry 4.0 initiatives as they introduce new technologies and processes for the business (Brown, et al., 2016). The change management strategies adopted within organisations should account for industry 4.0 initiatives for a successful implementation to be possible. In addition, these change management strategies should reflect the organisation's set goals and visions. Within the UK infrastructure sector, four main key change management initiatives were noted to deal with industry 4.0 initiatives, namely, (1) People, (2) Tools/Technologies, (3) Strategies, and (4) Processes (See Chapter 7 for more details). Industry 4.0 initiatives impact most, if not all, of the processes within the infrastructure construction process, this includes planning, operations, and maintenance (Jallow, et al., 2020). Introducing new processes and technologies would massively require a change in people, new competencies and capabilities will be introduced where staff resources may be required as new roles will be introduced. In addition to staff resources, the current staff within the organisation may need to increase capabilities to match the new processes and procedures as without the people integrating the Industry 4.0 initiative into their processes, a successful implementation may not be possible to achieve. Tools and technologies change is another required aspect to ensure a successful Industry 4.0 initiative implementation (Yu, et al., 2022), this is vital because without the right tools and technology to support the Industry 4.0 initiatives, it is impossible to implement Industry 4.0 initiatives. Strategic change is also recognised to be a key part of enabling industry 4.0 successful implementation, for instance, organisations need industry 4.0 initiatives and processes within their strategic goals, this is a key part of shaping the organisations' vision and providing guidance to managers and leaders on a plan of action on implementing industry 4.0 initiatives. Processes change is the final change to be considered, this is because Industry 4.0 initiatives will affect traditional processes that organisations will be using, industry 4.0 initiatives aim to conduct the same tasks with improved efficiency and productivity, hence traditional processes of these tasks will change to adapt to the new ways of working. Organisations' processes should align with industry 4.0 initiatives to enable successful implementation (see Chapter 7 for more details).

- ***Overcoming challenges blocking industry 4.0 strategies:*** This sub-process allows organisations to understand challenges that create barriers when it comes to the implementation of industry 4.0 initiatives. This process was divided into two stages: ***identifying the challenges*** and ***overcoming these identified challenges***. During the first stage, the challenges were identified while the inputs were being digested within the input process. This stage allows decision-makers within the organisations to understand the status of their organisation highlighting the gaps where there is a need for improvement to deal with these challenges. Upon completion of identifying the challenges, the GTMA was used to identify the most impactful challenges for organisations in the infrastructure sector (see Chapter 8 for more details). Industry 4.0 initiatives implementation disrupts business processes which may lead to organisations having doubts about having more risks than rewards through its implementation (Masood and Egger, 2019). In this study, six challenges were identified which are (1) Software and Hardware ***(Tools and Technologies challenges),*** (2) Knowledge and Understanding, (3) Resistance to change ***(People Challenges),*** (4) Organisational Culture ***(Processes Challenges),*** (5) Competency and Capabilities, and (6) Funding and Investment ***(Strategic Challenges).*** The second stage of this subprocess includes identifying how to overcome these challenges, this can be achieved through running focus groups and knowledge sharing across the organisation. Interaction between organisations can also be beneficial as different organisations are at varying levels in terms of industry 4.0 adoption, these must align with each organisation's vision and goals.

Within the infrastructure sector, the supply chain is key for the success of projects and operations as they are the most impactful and influential group towards the organisation's status within the fourth industrial revolution. Integrating industry 4.0 initiatives throughout the construction processes by an organisation provided confidence to the supply chain, for example, trust can be enhanced due to the use of digital tools such as the digital twin which can demonstrate the assets in their complete form before the asset is physically constructed. This allows members of the supply chain such as the community to visualised how the newly constructed asset will affect their community and improve respect between them and the organisation. Furthermore, for the organisation, their goal and visions are key to achieving them, outlining these at the start of a framework means that the challenges that may be faced will not be accounted for as they are unknown at this stage, hence the framework process may bounce back to the input process once challenges and barriers have been identified which were not foreseen prior.

OUTPUTS

During the third sup-process of the framework, the outputs that are gained from implementing Industry 4.0 initiatives are defined. The outputs outline the value that Industry 4.0 initiatives provide to organisations and their performance. See Chapter 9 for more details. In addition, the values highlighted can be used by organisations as a tool to measure the success of industry 4.0 strategies implementation. This stage within the sub-process has been split into three clusters represented by (1) environmental value, (2) economic value and (3) social value which is demonstrated in Figure 10.6.

Environmental value

The infrastructure sector's nature during construction and operation tends to impact the environment, Industry 4.0 initiatives aim to reduce this environmental impact which is vital as infrastructure is key in any economy. The introduction of Industry 4.0 initiatives to the infrastructure sector has assisted in the reduction of CO2 emissions, reduce energy consumption, and reduce waste as a contribution, these are to be measured to analyse the effectiveness of the environmental value of Industry 4.0 initiatives.

Economic value

Industry 4.0 initiatives have a direct influence on economic value especially within the infrastructure sector as it improves productivity, increase competitiveness for organisations and create innovative business models. Economic value encourages organisations to adopt Industry 4.0 initiatives which effectively impact both environmental and social value.

Social value

The infrastructure sector impacts social development as the community is the user of the infrastructure assets. Organisations Industry 4.0 initiatives directly positively influence social performance. Examples of social value can be seen in the stakeholder and supply chain relationships, increasing connectivity and social innovation.

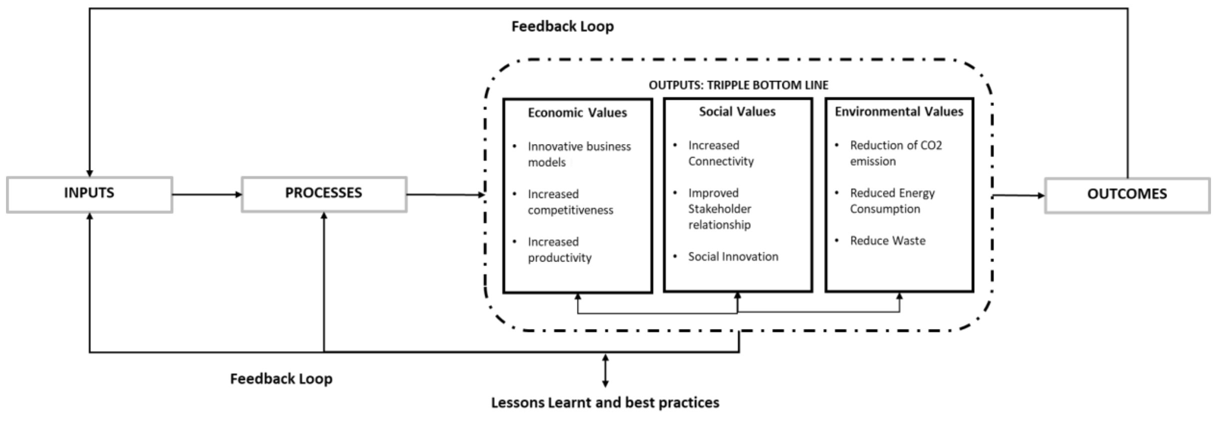


Figure 0.6: Outputs segment from the proposed framework

The output of the proposed framework is dependent on which Industry 4.0 initiative organisations aim to implement as each Industry 4.0 initiative varies in terms of technology and resource requirements, these must support the organisation's goals and vision. It is vital to measure the performance of these initiatives at this stage as it allows decision-makers can analyse what effect these initiatives have on stakeholders, assets, and operations. The key actions to be integrated within the output stage are:

- ***Observe the performance of the Industry 4.0 initiatives (KPIs)***: This stage comprises organisations monitoring and controlling the initiatives implemented. Key Performance Indicator management systems can be tailored to specific performance measures which are assigned to each of the organisation's goals (Jiang, et al., 2021). An interactive control system allows organisations to introduce new ideas while providing feedback strategically. These systems allow organisations' decision-makers to measure the performance of industry 4.0 initiatives compared to their initial objectives and vision. This also enables the organisations to make changes based on the performance results to suit their goals, these KPIs can either be negative or positive where achieving a numerical performance score can allow organisations to assess the value provided by the initiatives. Achieving these key performance indicators can allow higher management to make decisions based on what limits have been proven useful and non-useful within these initiatives implemented. It should also be taken into consideration that these key performance indicators present realistic targets that organisations can achieve. An example of these indicators can be the number of training hours provided to employees to improve their knowledge and awareness of Industry 4.0 initiatives. Another measure can be the use of the Industry 4.0 initiative, as these are technologies, their use will contain digital records which can be presented in the form of dashboards assessing interaction with the users.
- ***Assess the performance of the Industry 4.0 initiatives:*** During this stage the decision makers within the organisation can then either support or improve their decision on implementing Industry 4.0 initiatives based on the results that they have bothered in the previous stage. The performance outcomes are a significant factor in Industry 4.0 technologies' success for an organisation (Kumar, 2021). The assessment of the performance of Industry 4.0 initiatives can be identified by using the regression analysis as suggested by Kumar (2021). It should be noted that KPIs should be measured throughout the implementation and use of Industry 4.0 initiatives, this allows the

decision-makers to compare the initial performance of the initiatives as well as future performance. Having this comparison gives the decision-makers a clear vision of how the performance is being improved from the beginning of implementation and in the future. KPIs should be continuously monitored and reviewed throughout the use of these initiatives. Figure 10.7 demonstrates actions stop that ought to be integrated within the outputs.

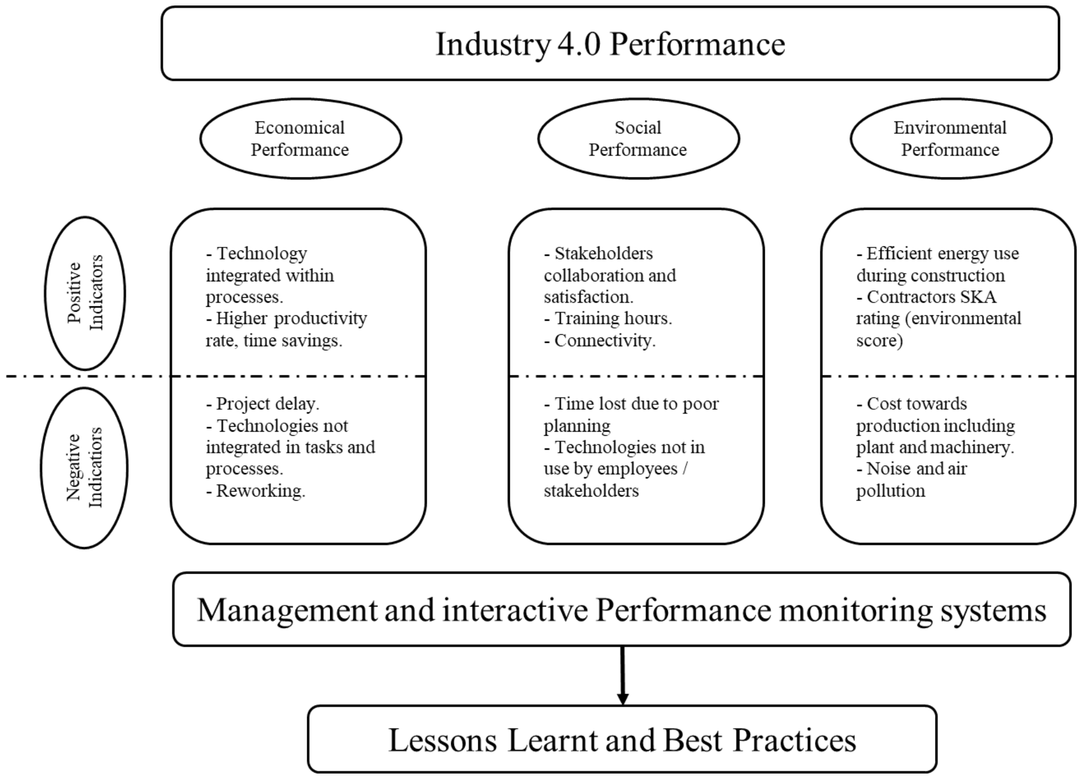


Figure 0.7: Examples of Evaluation of Industry 4.0 Performance

OUTCOMES

The final stage in the proposed framework is the outcomes of the Industry 4.0 initiatives. The stage during this stage, the 4.0 performance relating to the organisation's performance is represented in the form of the outcomes. The outputs represent the infrastructure sector benefits and values gained because of the implementation of Industry 4.0 initiatives. Five key lasting outcomes have been identified in this study, namely (1) increased productivity and efficiency, (2) competitive advantage, (3) increased revenue on projects, (4) improved stakeholder relationships and (5) net zero carbon emission, these are demonstrated in Figure 10.8. These values must be in line with the organisation's set goals to provide value which is why a measurement system of these values is to be adopted to aid higher management in decision-making.

- ***Increased productivity and efficiency:*** Industry 4.0 initiatives can enable organisations in the infrastructure sector to achieve a more productive and efficient construction process by using digital and automation tools to plan the best solutions and productive and efficient processes.
- ***Competitive advantage:*** Implementing industry 4.0 initiatives can lead to organisations gaining a competitive advantage as they can gain skilled resources and innovative solutions to benefit both the organisation and the supply chain. This leads to the supply chain being more confident in the organisation.
- ***Increased revenue on projects:*** Organisations can gain financially through the implementation of Industry 4.0 initiatives through the reduction of costs and increased efficiency of their processes. The Industry 4.0 initiatives can enable the best solutions for the projects to be noted ahead of the planned tasks being conducted reducing rework and inefficient work processes.
- ***Improved stakeholder relationships:*** The infrastructure sector is heavily dependent on its stakeholders; industry 4.0 initiatives include technological advances and virtual means where stakeholders can better understand the project itself improving understanding for stakeholders such as the client and communities.
- ***Net zero carbon emission:*** Industry 4.0 initiatives tend to use big data, this can enable organisations to calculate the environmental impact and assess the best solutions for lower carbon emission, additionally, this helps in improved relationships with the community due to pollution control and reduction of waste.

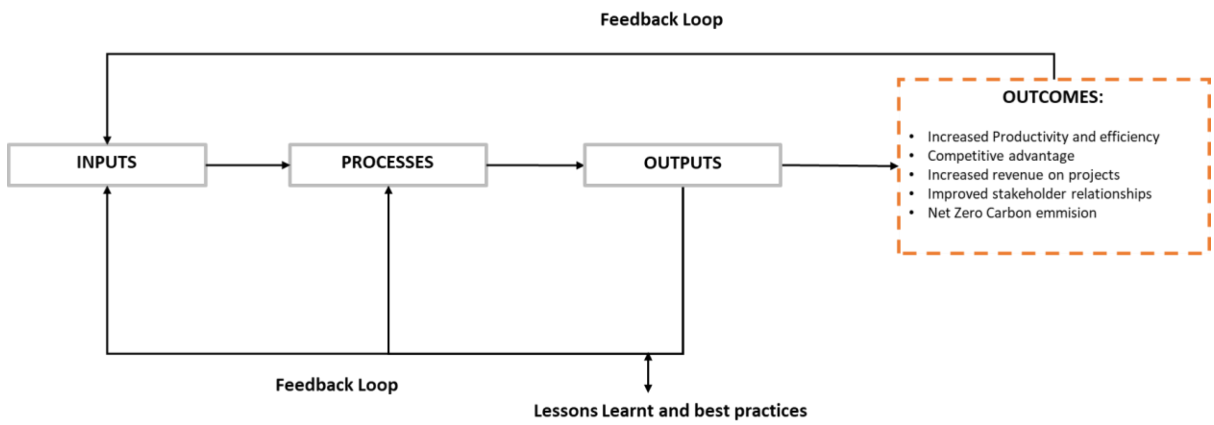


Figure 0.8: Outcomes stage of the proposed integrated framework

During this stage, the main activity should be measuring the values provided by the Industry 4.0 initiatives regardless of the organisations' goals as the values may differ from their vision while proving to be valuable for the organisation.

MEASURING INDUSTRY 4.0 VALUES

The long-term values for organisations that have been gained through industry 4.0 initiatives being implemented should be noted to understand the success of their implementation. This enables higher management to have evidence for their decision and assess the financial gain and their position within the sector. This measurement can impact the potential to adopt and implement more industry 4.0 initiatives in future which is why it is a necessity to measure the finances of the investors involved.

Within the framework, the outputs have an impact on each stage as seen in the feedback loop. The feedback enables improvement after evaluation of the performance of the initiatives, where understanding the outputs whether positive or negative can allow the organisations to alter the strategy if negative to achieve a positive outcome.

10.7. MAPPING PROPOSED INTEGRATED FRAMEWORK TO OSTERWALDER'S BUSINESS MODEL CANVAS

Businesses need to adapt their business models to become successful in new processes, these changes may be beneficial for the business in terms of raising competitive advantage, government laws or innovative progression. Wirtz et al (2010) assert that business model updates for organisations are key to the successful implementation of new processes as it details ways in which the business creates value and the channels to do so with the new process to be implemented (Wirtz, et al., 2010). Mohelska and Sokolova (2018) suggest that due to these new processes and changes introduced, managerial approaches should also change to accommodate these changes, in addition, organisations' business models should change and adapt to the new processes introduced within the organisation (Mohelska and Sokolova, 2018).

The business model identifies the business activities that can integrate with the new processes and highlight the resources required to achieve their goals. During the systematic literature review, the different Business models were evaluated. There is a research gap in terms of business model innovation frameworks for industry 4.0 initiatives for the UK infrastructure sector. For this study, Osterwalder's business model Canvas was used and tailored for this study mapping to the proposed integrated framework. Figure 10.9 demonstrates an example of implementing Artificial intelligence as one of the industry 4.0 initiatives with Osterwalder's business model Canvas:

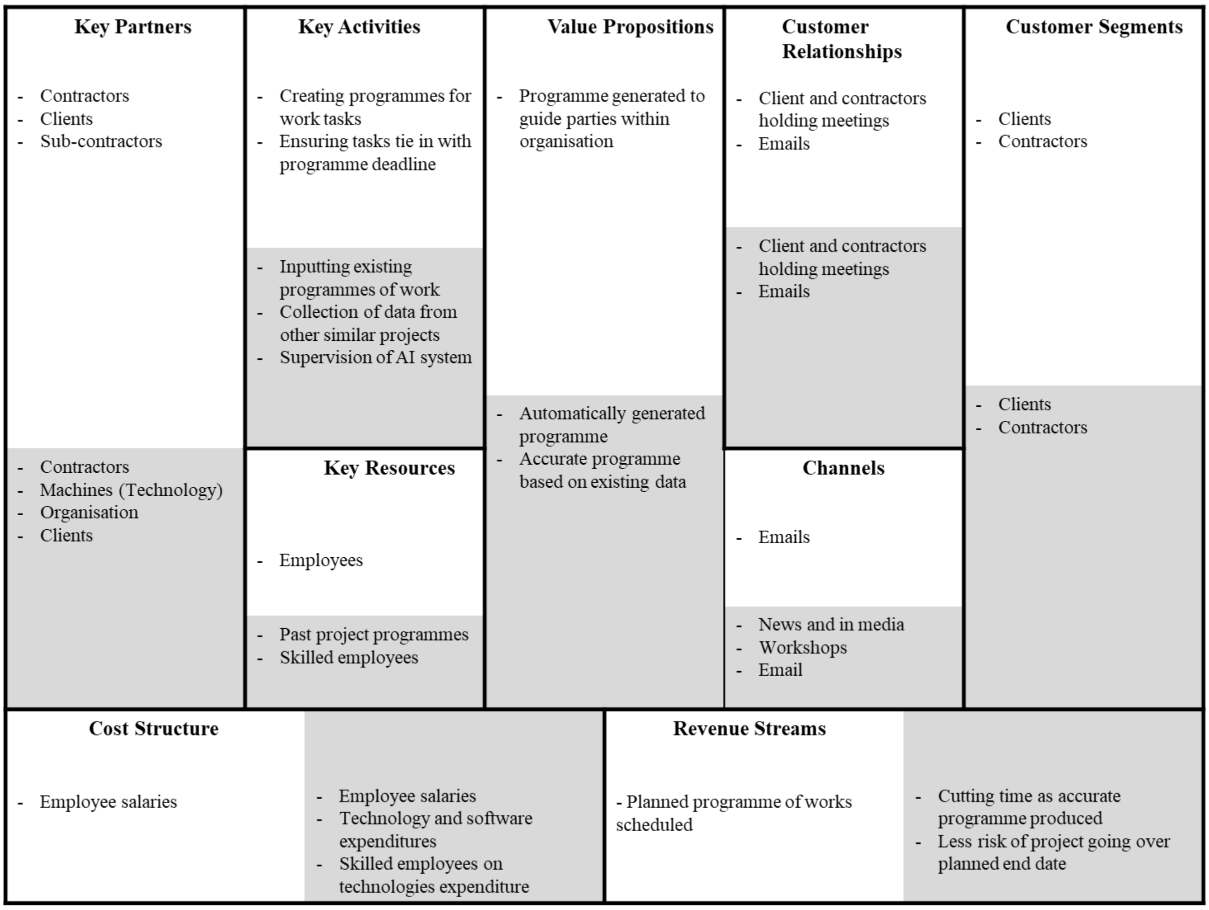


Figure 0.9: Canvas for predicting work practices vs. work practices created with AI.

10.8. EVALUATION OF THE INTEGRATED BUSINESS MODEL FRAMEWORK

The evaluation process of the business model framework incorporates the proposed framework into Osterwalder's Business Model Canvas. This process follows a qualitative approach where the interviews were conducted with experts from the UK infrastructure sector. The term "Evaluation" can be defined as *"a rigorous and structured assessment of a completed or ongoing activity, intervention, programme or policy that will determine the extent to which it is achieving its objectives and contributing to decision-making"* (Menon, et al., 2009). Jimenez-Contreras et al (2003) have asserted that evaluation of research is necessary as it allows the research findings to be assessed on their quality, in addition, the evaluations allow a wider analysis as the research only accounts for a portion of people that have taken part in the study (EvaristoJiménez-Contreras, et al., 2003). In this study, the evaluation was conducted through the interviewing of five experts within the UK infrastructure sector with a minimum of ten years' experience, the experts were from different organisations to gain perspective from differing organisations.

Interviews were conducted virtually through Microsoft Teams and the evaluation protocol was shared with the interviewees which outlined the questions where participants could provide comments on the framework proposed (Evaluation protocol available in Appendix E). Five questions were presented to assess the workflow of the proposed framework where the usefulness and clarity of the framework could be highlighted. Additionally, the interviewees were free to provide any comments and feedback on the proposed framework. The interviewees highlighted that the proposed framework would be of use within the UK infrastructure sector as it highlights the challenges and outcomes of industry 4.0 initiatives which are not clear within the organisations, especially throughout the supply chain. They have pointed out that the framework would allow their organisations in understanding the change management practices undertaken as most of the organisations have adopted industry 4.0 initiatives however the implementation of these initiatives is struggling due to challenges and no clear route of what changes to undertake to overcome them.

10.9. RATIONALE OF THE INDUSTRY 4.0 READINESS TOOL

Industry 4.0 implementation still proves to be a challenge within the UK infrastructure sector and the decision-makers within organisations in the sector despite its clear importance as it introduces several changes to the organisation's structure, processes and business practices (see Chapter 7 for more detail). Due to the challenges and lack of understanding in the sector, it is vital for change management to be highly considered in the decision-making process of implementation of Industry 4.0 initiatives to ensure successful implementation. It has been highlighted that organisational culture and resistance to change is a key barrier to successful implementation which should be addressed before organisations implement Industry 4.0 initiatives (Vuksanović Herceg, et al., 2020); (Horvath and Szabo, 2019); (Schneider and Sting, 2020); (Eyel and Mete, 2021). Saraji et al (2021) argue that "resistance to change" has not been classified as a nonessential challenge as resources and competency seems to be the key barrier blocking Industry 4.0 implementation for organisations (Saraji, et al., 2021). Additionally, James et al (2022) state that assessing organisations' resources are key within an industry and the management of these resources is vital for implementing new processes which may require new capabilities (James, et al., 2022). Authors have proposed the development of a readiness tool to assess organisations' readiness to implement Industry 4.0 initiatives before implementation. The evaluation of readiness for organisations allows the decision-makers to bridge the gaps if they can on the changes and challenges that are presented by Industry 4.0 initiatives (Machado, et al., 2019).

Industry 4.0 readiness has been explored within research, this began in 2015 when an "industrie 4.0 readiness model" has been presented by IMPLUS (Foundation of the German Engineering Federation) (Trstenjak, et al., 2022). According to the authors, the evaluations of readiness for organisations are vital as decision-makers and employees can address the changes to be made with new processes, this can be achieved by calculating the organisation's readiness factor which can include the maturity of the organisation in terms of industry 4.0 initiatives. Furthermore, within an organisation, the readiness may vary from team to team, as within the infrastructure sector, organisations contain various teams who specialise in different aspects. Organisations within the sector may have a digital team who would be at a higher level of readiness to implement these initiatives compared to the site team for example who are mainly on site and do not have a lot of digital capabilities, hence it is vital to assess readiness across all teams within the organisation (Castelo-Branco, et al., 2019).

10.10. DEVELOPMENT OF THE CHANGE READINESS DIAGNOSTIC TOOL THROUGH INDUSTRY 4.0 TRANSFORMATION JOURNEY

Developing the readiness tool for this study was broken into stages where the initial two stages include conducting a literature review of developed readiness tools to form a basis for the tool to be developed. The systematic literature review was conducted finding research studies on the following platforms: Directory of Open Access Journals, Scopus, ProQuest, SpringerLink, Elsevier and Scholar. While searching for literature the criteria were filtered to published research between 2010 and 2022 which returned a total of 56 publications that have been published on readiness tools. To further the search, keywords were added to the search filter to assess research relating to (1) Industry 4.0 initiatives readiness, (2) different levels within an organisation, and (3) the gathered results from this study. From the evaluation of the publications, it was decided to develop a readiness tool that can be used before the implementation of Industry 4.0 which can allow organisations to assess their readiness for implementing the initiative, the readiness tool has been developed as a survey. IMPULS (Foundation of the German Engineering Federation)'s "Industrie 4.0 Readiness" model (2015) was used as a base of this study and was enhanced to tailor to this study as the readiness tool developed by IMPLUS is only tailored to ***Manufacturing*** and ***Mechanical Engineering***, this has been chosen as the characteristics highlighted within this model suite the requirements for this study.

IMPULS (2015) highlighted six factors which should be taken into consideration and have readiness factors measures which are (1) employees, (2) strategy and organisation, (3) smart factory, (4) smart operations, (5) smart products, and (6) data-driven services. These are among

18 other items which determine the readiness level of an organisation. These six factors relate to the organisation's employee skill sets, revenue, innovation management and data analytics, just to name a few. These highlight the organisation's context in terms of its characteristics and structure where they may need changes to allow for a successful implementation. Additionally, their internal resources and capabilities required for the changes introduced by Industry 4.0 will also be assessed. Following the factors highlighted by IMPULS (2015), the following factors were identified for the survey developed to assess readiness, (1) Organisation's Needs, (2) Organisations willingness to change (3) Employee's willingness to change (4) Support from management (5) Organisations productiveness, and (6) Organisations willingness to invest. These factors have been described in the following sections below, the readiness tool developed aims to measure individual organisations' readiness within the infrastructure sector to adopt the changes required through the journey of industry 4.0 transformation. The measuring criteria are as follows:

Table 0.2: Measuring criteria for readiness tool.

Measure	Description
1	Not distinguished – never happens
2	Slightly distinguished – at times happens
3	Distinguished – occasionally happens
4	Very distinguished – frequently happens
5	Highly distinguished – always happens

ORGANISATIONS NEED

The organisation's compatibility and need for new procedures and processes are vital for implementing Industry 4.0 initiatives, which makes this factor a key part of Industry 4.0 readiness. Florescu and Barabas (2022) argue that organisations need tools which are compatible and necessary within the industry 4.0 technologies scope that is aimed to be implemented to allow the possibility of creating a framework to suit the specific initiative that has been chosen for implementation (Florescu and Barabas, 2022). In addition to the technological compatibility, the business itself is required to need to implement these initiatives which ensure successful or unsuccessful implementation. Six criteria were identified to measure the organisation's need for industry 4.0 implementation.

Table 0.3: Questionnaire associated with Organisations needs evaluation.

Organisation Need: consists of the extent to which the organisations employees feel that there is a necessity for industry 4.0 initiatives						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	There are valid reasonings to implement industry 4.0 initiatives (e.g., government laws, clients' requirements)					
2	There are business requirements that need industry 4.0 initiatives to be implemented (e.g., competitiveness, stakeholder specifications)					
3	The reasons for implementing industry 4.0 initiatives (e.g., improving productivity, increasing efficiency)					
4	Resources are being invested in for industry 4.0 initiatives to be conducted efficiently (e.g., competent resources, technologies)					
5	The organisation has a good reason to adapt to industry 4.0 initiatives (e.g., economic value, social value)					
6	The reason for implementing Industry 4.0 initiatives has been made clear to me.					

The score for the organisation's need has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly about the need for industry 4.0 initiatives to be implemented.
- **24** – **19:** The member of the organisations feels somewhat that there is a need for industry 4.0 initiatives to be implemented.
- **18** – **13:** The member of the organisations feels there is a slight need for industry 4.0 initiatives to be implemented.
- **< 12:** The member of the organisation feels there is no need for industry 4.0 initiatives implementation.

ORGANISATIONS' WILLINGNESS TO CHANGE

Organisations need to be ready for the changes with any new processes and initiatives adopted, Prodi et al (2022) argue that Industry 4.0 initiatives change three main aspects which are technologies, organisational and human aspects which is why organisational flexibility ton these changes need to be highlighted before implementation (Prodi, et al., 2022). The study findings have highlighted that the infrastructure has major challenges when it comes to resistance to change throughout the organisation (see Chapter 7 for more details). Furthermore, industry 4.0 initiatives require the entire organisation to be on the same page and adopt this change throughout as the initiatives affect processes within the organisation which may involve procedures for the entire supply chain. Six criteria were identified to measure the organisations' willingness to change for Industry 4.0 implementation.

Table 0.4: Questionnaire associated with Organisations' willingness to change evaluation.

Organisations' willingness to change: consists of the extent to which the organisations are willing to change for industry 4.0 initiatives						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	The organisation think that industry 4.0 initiatives implementation can benefit the organisation.					
2	Implementation of industry 4.0 initiatives will provide more efficient and effective processes for the organisation.					
3	The implementation of Industry 4.0 initiatives will better our everyday tasks as an organisation.					
4	The organisation is willing to gain knowledge and understanding of the new processes introduced by implementing industry 4.0 initiatives.					
5	Training and upskilling for industry 4.0 initiatives can and will be provided to upskill employees.					
6	The organisation will get the resources that are required for industry 4.0 initiatives implementation.					

The score for the organisation's willingness to change has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that their organisation is willing to change for industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisations feels somewhat that their organisation is willing to change for industry 4.0 initiatives to be implemented.
- **18 – 13:** The member of the organisations feels there is a slight chance that their organisation is willing to change for industry 4.0 initiatives to be implemented.
- **< 12:** The member of the organisation feels there is no chance that their organisation is willing to change for industry 4.0 initiatives implementation.

EMPLOYEE'S WILLINGNESS TO CHANGE

Mishra and Venkatesan (2020) assert the need that employees to accept the changes that are introduced with industry 4.0 initiatives implementation (Mishra and Venkatesan, 2020). Introducing industry 4.0 initiatives within the infrastructure sector can create personal feelings towards the changes among the employees in the organisation. This is due to the uncertainty of the new procedures and the confidence of the employees with the new competencies and capabilities introduced. Additionally, the communication of these new changes from Industry 4.0 initiatives is key for a successful implementation as employees will have concerns about the disruption to their processes. Six criteria were identified to measure the employee's willingness to change for Industry 4.0 implementation.

Table 0.5: Questionnaire Associated with Employee's Willingness to change evaluation.

Employees' willingness to change: consists of the extent to the employees are willing to change for industry 4.0 initiatives implementation						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	I think that industry 4.0 initiatives implementation can create personal benefits.					
2	Implementing industry 4.0 initiatives can allow the enhancement of my capabilities.					
3	I can gain future benefits through the implementation of Industry 4.0 initiatives in my organisation.					

4	I think I can gain advantages in my career if my organisations implement industry 4.0 initiatives.					
5	I am not in fear of my position and status in the organisation when it implements industry 4.0 initiatives.					
6	I think I have the capabilities to learn new ways of working and processes when my organisation implements industry 4.0 initiatives.					

The score for employees' willingness to change has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that they can benefit from industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisations feels somewhat that they can benefit from industry 4.0 initiatives to be implemented.
- **18 – 13:** The member of the organisations feels there is a slight chance that they can benefit from industry 4.0 initiatives being implemented.
- **< 12:** The member of the organisation feels there is no chance that they can benefit from industry 4.0 initiatives implementation.

SUPPORT FROM MANAGEMENT

Management involvement can massively impact the success of the implementation of Industry 4.0 initiatives within the infrastructure sector. The support from management allows supportive channels for employees and the rest of the organisation increasing confidence in the parties involved in the implementation. Villalba-Diez and Ordieres-Mere (2021) argue that industry 4.0 initiatives require management within organisations to have strategies that are in place to accommodate the changes (Villalba-Diez and Ordieres-Mere, 2021). In this study, it has been highlighted that it is of major importance that management and senior leaders are to be involved in the implementation of industry 4.0 initiatives within the UK infrastructure sector. Managers and leaders are responsible for communicating the innovative goals and vision of industry 4.0 initiatives to the employees and lead as an example in overcoming challenges and enhancing knowledge and awareness, hence support from managers is a critical factor in measuring organisations' readiness for industry 4.0. Six criteria were identified for the tool proposed to measure the support from management for industry 4.0 implementation.

Table 0.6: Questionnaire associated with Support from management evaluation.

<table>
<tr><td colspan="7">Support from management: consists of the extent to which the members of the organisation feel that management within the organisation is dedicated to providing support Industry 4.0 initiatives implementation or otherwise.</td></tr>
<tr><td colspan="2" rowspan="2">Criterion</td><td colspan="5">Score</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>1</td><td>Higher management in the organisation has been clear on the organisation implementing industry 4.0 initiatives.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>Higher management has been leading by example when it comes to industry 4.0 initiatives.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>The leaders in the organisation are committed to successfully implementing industry 4.0 initiatives.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>Higher management has been involved in processes and changes involved with industry 4.0 initiative implementation.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>The organisation has been providing the resources and training needed and higher management has been pushing upskilling for industry 4.0 implementation.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>Managers and leaders have communicated and encouraged the implementation of industry 4.0 initiatives within the organisation.</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

The score for support from management has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that managers within the organisation are committed to supporting industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisation feels somewhat that managers within the organisation are committed to supporting industry 4.0 initiatives to be implemented.
- **18 – 13:** The member of the organisation feels there is minimal effort from managers within the organisation showing commitment to supporting industry 4.0 initiatives to be implemented.
- **< 12:** The member of the organisation feels there is no chance that managers within the organisation are committed to supporting industry 4.0 initiatives implementation.

ORGANISATION PRODUCTIVENESS

Industry 4.0 initiatives implementation directly affects an organisation's productiveness. The implementation of industry 4.0 initiatives may disrupt the business depending on how ready the organisation is to implement these initiatives and effectively impacts the readiness itself as well as impactive productivity in a positive way if such disruptive factors do not happen (Koh, et al., 2019). This study has highlighted that industry 4.0 initiatives implementation within the infrastructure sector provides environmental, social, and economic value (see Chapter – for more details). Furthermore, the understanding of the value industry 4.0 initiatives introduce has been recognized and key factors in encouraging successful implementation of industry 4.0 initiatives. Six criteria were identified for the tool proposed to measure the value from employees' point of view for industry 4.0 implementation.

Table 0.7: Questionnaire associated with Organisations' productivity evaluation.

Organisations productivity: consists of the extent to which the members of the organisation feel that their organisation would gain value from implementing industry 4.0 initiatives.						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	I think that the organisation can gain value from implementing Industry 4.0 initiatives.					
2	The organisation can save costs and be efficient through the implementation of Industry 4.0 initiatives.					
3	Stakeholder relationships with the organisation can be enhanced by implementing industry 4.0 initiatives.					
4	Overall productivity and efficiency can be enhanced with the implementation of Industry 4.0 initiatives.					
5	The organisation can be highly respected within the sector through industry 4.0 initiatives implementation.					
6	The organisation can save time on projects leading to gaining profit through the implementation Industry 4.0 initiatives.					

The score for organisations' productivity has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that their organisation will gain value Industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisations feels somewhat that their organisation will gain value if Industry 4.0 initiatives are to be implemented.
- **18 – 13:** The member of the organisations feels there is a slight chance that their organisation will gain value if Industry 4.0 initiatives are to be implemented.
- **< 12:** The member of the organisation feels there is no chance that their organisation will gain value Industry 4.0 initiatives implementation.

ORGANISATIONS' WILLINGNESS TO INVEST

The implementation of Industry 4.0 initiatives requires heavy investment for both the technologies involved with the initiatives, resources, and upskilling. Decision-makers within organisations need to focus on the investment of tools/technologies and capabilities to assist in the complexities introduced by Industry 4.0 initiatives. Bosman et al (2020) assert the need for investment in Industry 4.0 initiatives as it benefits organisations by raising their competitiveness within their sector (Bosman, et al., 2020). In this study, it has been noted that investment in industry 4.0 initiatives has been seen as a major challenge within the UK infrastructure sector (see Chapter – for more detail). Therefore, organisations need to assess their readiness to invest in these initiatives which are vital for the successful implementation of industry 4.0 initiatives. Six criteria were identified for the tool proposed to measure the organisations' willingness to invest in Industry 4.0 implementation.

Table 0.8: Questionnaire Associated with Organisations' Willingness to invest evaluation.

Organisations' willingness to invest: consists of the extent to which the members of the organisation feel that their organisation would invest in the necessary tools for implementing industry 4.0 initiatives.						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	I think that the organisation can provide adequate training in implementing Industry 4.0 initiatives.					
2	I believe that the organisation will provide the technology required for the implementation of Industry 4.0 initiatives.					
3	The organisation can get the required licences for the entire supply chain when implementing Industry 4.0 initiatives.					

4	The organisation will invest in the necessary resources for the implementation of Industry 4.0 initiatives.					
5	The organisation can be trusted to support and provide any financial requirements for industry 4.0 initiatives implementation.					
6	The organisation will provide the tools needed to successfully adopt the implemented Industry 4.0 initiatives.					

The score for organisations willing to invest has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that their organisation is willing to fully invest in industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisations feels somewhat that their organisation is willing to invest in industry 4.0 initiatives to be implemented.
- **18 – 13:** The member of the organisations feels there is a slight chance that their organisation is willing to invest in industry 4.0 initiatives to be implemented.
- **< 12:** The member of the organisation feels there is no chance that their organisation is willing to invest in industry 4.0 initiatives implementation.

OVERALL SCORE

For the measurement of each organisation's Industry 4.0 readiness, an example gathered from an organisation going through the questions and evaluating the final readiness factor with the above questionnaire is necessary. This was conducted where the overall score gathered from the six questions above was calculated based on the employee's view of their organisation's position for Industry 4.0 readiness. It was decided that an overall score of closest to 150 would mean that the organisation is advanced in readiness to adopt industry 4.0 initiatives.
The readiness scores for Industry 4.0 measurement are demonstrated below:

- **150 – 125:** The organisation is extremely ready to implement industry 4.0 initiatives.
- **124 – 99:** The organisation is very ready for industry 4.0 initiatives implementation.
- **99 – 74:** The organisation is slightly ready to implement Industry 4.0 initiatives - **< 73:** The organisation is not ready to implement industry 4.0 initiatives.

10.11. EVALUATION OF THE INDUSTRY 4.0 READINESS TOOL

The Industry 4.0 readiness tool was evaluated following the same processes as the evaluation of the framework that has been described in Chapter 4. The five experts who took part in the framework evaluation were interviewed for the Industry 4.0 readiness tool as both evaluations were conducted in the same interview. The questions presented to the participants were included in the evaluation protocol (presented in Appendix F) where the questions were tailored to allow the participants to review the readiness tool. The interviewees expressed that the tool was easy to follow and use and they highlighted that the readiness tool presented clear values their organisations can gain through industry 4.0 initiatives, they also highlighted that the readiness tools outline certain aspects that their organisation is not aware of in terms of being ready to implement these initiatives which allows them to plan accordingly before implementation.

The experts that took part in the readiness tool and framework evaluation also provided valuable input towards altering the framework, 80% of the experts that took part in the study felt that the initial structure of the framework needed to be rearranged as initially within the framework process section, the link between the change management processes and the challenges process was a one-directional arrow moving from the change management process to the challenge process. It was recommended that the arrow should be a two-directional arrow as the challenges would feed into what change management process the organisation needs to adopt and implement across the organisation. It was highlighted that depending on the challenges being faced, the organisation needs to keep updating their change management strategies to avoid and maintain these challenges. Furthermore, the change management process was initially presented in a tabular format. The experts felt that the change management process should be presented in a different way as they all feed into each other. The experts expressed that organisations need to create a strategy for digitalisation within their organisation. Once the strategy has been set, there should be a clear outline on what tools and technologies will be required and to which processes suits their visions and goals. Finally, with the understanding of the tools and technologies required, the organisation can then upskill their people to increase their competencies and capabilities for the tools and technologies adopted can be used efficiently gaining value.

The experts expressed that the outputs and outcomes processes within the framework were greatly presented as it outlines what outcomes they could visualise for the outputs as most of them felt that their organisations mainly focus on the outputs gained such as increased productivity or reduced CO_2 emissions but mostly fail to visualise the outcomes instead. This is mostly due to the nature of the infrastructure sector being organisations are split into different projects which have different requirements and goals. This has made the experts feel that this framework could encourage organisations to visualise beyond their singular project within an entire organisation and assess the potential outcomes of adopting industry 4.0 strategies.

10.12. SUMMARY

In this chapter, an integrated framework for the implementation of Industry 4.0 initiatives has been discussed, this was then mapped into a business model framework leading to the development of the Industry 4.0 readiness tool. The framework and readiness tool were created based on the findings within this study and the literature review conducted. The proposed framework can be used by organisations within the UK infrastructure sector who plan on implementing Industry 4.0 initiatives and organisations who have adopted Industry 4.0 initiatives but are struggling to achieve successful implementation within their projects. The framework allows higher management and the decision-makers within the organisation to fully understand the requirements for these initiatives and how to manage aspects such as change for these initiatives. Additionally, the readiness tool has been developed to enable organisations within the sector to evaluate their readiness in implementing Industry 4.0 initiatives to gain a successful implementation.

CHAPTER 11: CONCLUSION AND FUTURE RECOMMENDATIONS

11.1. INTRODUCTION

In this chapter, the conclusions and future recommendations from the research are presented. The chapter initially shares the research process of the study while explaining the research aim and objectives and the research questions. Recommendations are then highlighted and then followed with future recommendations. The key discoveries are explored concerning the research objectives.

11.2. RESEARCH PROCESS

Table 0.1: Research process summary

Aim of research	To assess the UK infrastructure sectors industry 4.0 strategies implementation status to enhance competitive advantage
Research objectives	1. To explore the prospect of industry 4.0 strategies in general and the UK infrastructure sector. 2. To investigate the key drivers for embracing Industry 4.0 strategies in the UK infrastructure sector. 3. To explore and understand the key Industry 4.0 strategies implemented in the infrastructure sector. 4. To investigate the challenges for adopting Industry 4.0 strategies in the infrastructure sector. 5. To investigate the key leading change strategies those have been adopted in the UK infrastructure sector to embrace Industry 4.0 concepts. 6. To explore potential benefits of adopting Industry 4.0 strategies in the infrastructure sector.

	7. To develop and evaluate the industry 4.0 business model framework.
Research questions	1. What is the status of industry 4.0 strategies in general within the infrastructure sector? 2. What are the key drivers that have fuelled the need for embracing Industry 4.0 agenda in your organisation? 3. What is the relationship between the key drivers? 4. What are the key 'Industry 4.0 strategies' that are currently being adopted within the infrastructure sector? 5. What is the current level of implementation of industry 4.0 strategies within the infrastructure sector? 6. What are the main challenges the infrastructure sector faced by organisations when implementing Industry 4.0 agenda? 7. What is the most influential challenge that the infrastructure sector face in implementing industry 4.0 agenda? 8. What are the key change management strategies being implemented within organisations in the infrastructure sector to manage Industry 4.0 agenda issues? 9. What are the efforts that Industry 4.0 agenda has contributed to organisations within the infrastructure sector?

	10. Is there a need for developing an innovative business model for adopting Industry 4.0 agenda within the infrastructure sector?
Classification of research	Exploratory research
Research philosophy	Pragmatism
Research approach	Inductive approach
Research methodology	Qualitative study
Research strategy	Grounded theory
Collection of data	Semi-structured interviews and systematic literature review
Research sampling method	Snowball and purposive sampling methods
Quantity of participants	21
Participant sampling diversity	BIM coordinators, Digital leads, GIS managers, Survey manager, Head of BIM, Design managers, Quantity surveyors, BIM managers, and Site engineers
Data analysis	TISM, Thematic analysis, GTMA, Fuzzy MICMAC and Maturity model
Outputs of research	Integrated Business model framework for implementation of industry 4.0 initiatives within the UK infrastructure sector. Industry 4.0 readiness tool for implementing industry 4.0 strategies within the UK infrastructure sector.

11.3. KEY RESULTS

Objective 1: 1) To explore the status of the UK infrastructure sector and industry 4.0 strategies.

Research Question 1: What is the status of Industry 4.0 strategies in general within the infrastructure sector?

The UK infrastructure sector is at a rise in development as the population is growing and infrastructure needs to be developed and constructed to accommodate for this population growth and provide value to the economy. The development of infrastructure consists of a variety of challenges, especially with climate change, smart solutions that are environmentally friendly are required as infrastructure construction is one of the main contributors to emissions. In 2016, the UK government mandated an Industry 4.0 strategy with the rules being all public sector projects over £10,000,000 and project duration of 12 months minimum must implement a minimum of Level 2 BIM (Building Information Model), the UK government provided standards such as BS1192-2, PAS1192 and ISO19650. This has resulted in many large organisations in the infrastructure sector achieving digital solutions and creating more efficient processes. However, some organisations are still to fully implement the Industry 4.0 initiative.

Despite the BIM level 2 mandate and standards provided, the UK government or any other governing bodies and institutions are yet to mandate or instil any other Industry 4.0 initiative for any industry and sector.

Objective 2: To investigate the key drivers for embracing Industry 4.0 strategies in the UK infrastructure sector.

Research Question 2: What are the key drivers that have fuelled the need for embracing Industry 4.0 agenda in your organisation?

Six key drivers were identified that are influencing the implementation of Industry 4.0 strategies within the UK infrastructure sector. The multi-theory approach was adopted using institutional theory and the resource-advantage theory in the view of the organisations. the key drivers identified were split into two groups which were the internal drivers which include Increased Finance and Performance, Increased Productivity, and Innovation. The other group was external drivers grouped into Coercive pressures from Government laws, Normative pressures containing Competitiveness, and Mimetic pressures which included Client demand.

Research Question 3: What is the relationship between the key drivers?

In this study, the relationship between the key drivers was explored, and it was discovered that the key drivers contain different powers and impacts on the organisations. for the establishment of the relationships, the TISM methodology was adopted to map the relationships as they are complex. Competitiveness was noted as the most impactful driver which was at the bottom of the TISM hierarchy and identified as the most impactful driver. Client Demand, Increased Finance and Performance, and Increased Productivity were identified to be the least impactful drivers for organisations within the UK infrastructure sector. Following the TISM which identified the dependence and driving powers of the drivers, the drivers were analysed using the Fuzzy MICMAC analysis method where Government laws were found as the most powerful key driver regarding the implementation of industry 4.0 initiatives in the UK infrastructure sector.

Objective 3: To explore and understand the key Industry 4.0 strategies implemented in the infrastructure sector.

Research Question 4: What are the key 'Industry 4.0 strategies' that are currently being adopted within the infrastructure sector?

According to the BIM level 2 minimum BIM mandate which includes data and digitisation, the UK infrastructure sector has adopted some industry 4.0 strategies within their organisational processes. It has been revealed that six main industry 4.0 initiatives have been implemented within the UK infrastructure sector organisations. 3D models, Big Data, BIM, GIS, Drones, Point Clouds and Digital surveys have been identified as the key strategies implemented. These strategies are all within the BIM level 2 mandate scope where 3D models providing a virtual representation of the asset are mandatory. Additionally, the models included within BIM level 2 must contain a certain criterion of data where organisations are pushing for big data to make more use of the initiative rather than just the data required to be in line with the BIM mandate. Organisations have also implemented using drones, point clouds and digital surveys as initiatives to have more efficient ways of working. Drones are being used for monitoring site progress. And point clouds and digital surveys are a source of real-time data which could be utilised in various ways for the organisation's projects. The aim for organisations in implementing these initiatives is to both abide by government laws and improve efficiency and productivity for their organisation, hence increasing competitiveness.

Research Question 5: What is the current level of implementation of Industry 4.0 strategies within the infrastructure sector?

An industry 4.0 maturity model was developed to assess the level of maturity of the organisations that took part in this study with their level of industry 4.0 implementation. In this study, the level of implementation altered and depended mostly on the size of the organisation and the capabilities and competency of resources available within the organisation. Four large organisations fell in level 3 within the maturity model for the implementation of BIM and 3D models, the fifth large organisation was categorised at level 0 as well as all the small to medium-sized organisations. regarding the level of implementation for Big Data, only 2 large organisations fell in level 3 implementation, the rest of the organisations were within the medium to lower levels of implementation. Regarding point clouds and digital surveys, and drones, only one organisation was at a high level of implementation, the remaining organisations were between medium and lower levels. GIS implementation was like BIM and 3D models implementation where three of the large organisations are at the highest level of implementation, the other two large organisations are at a medium level of implementation and all small to medium-sized organisations were at a low level of implementation. The findings showed that despite the available initiatives, the level of implementation shows that there is a lack of implementation of the initiatives, even the mandated initiative by the UK government where some large organisations do not have the initiative implemented. This required immediate attention to enhance industry 4.0 status within organisations within the sector.

Objective 4: To investigate the challenges of adopting Industry 4.0 strategies in the infrastructure sector.

Research Question 6: What are the main challenges the infrastructure sector faced by organisations when implementing Industry 4.0 agenda?

Six main challenges were identified in this study creating a barrier in the implementation of industry 4.0 initiatives in the UK infrastructure sector. These challenges include software and hardware, knowledge and understanding, organisational culture, resistance to change, competency and capabilities, and funding and investment. The knowledge of these challenges can assist decision-makers within the organisations to understand the barriers and can aid in implementing the right initiatives that suit the barriers they contain within their organisation to gain value. The challenges also highlight the lack of resources and capabilities organisations face when implementing these initiatives.

Research Question 7: What is the most influential challenge that the infrastructure sector face in implementing Industry 4.0 agenda?

In addition to the identification of these challenges, an attempt to quantify these challenges was also undertaken using the Graph Theory Matrix Approach. "Software and Hardware" was found to be the most impactful challenge blocking organisations from implementing industry 4.0 initiatives within the UK infrastructure sector. This is because software and hardware for these initiatives can tend to be very costly where organisations resist investing, additionally, organisations that have invested in the software and hardware would also need to provide licences for the employees where organisations purchase a limited number of licences leading to not the whole organisations being able to use the initiatives to its full capacity. The second most impactful challenge was "organisation culture", this challenge is due to organisations not having a clear vision of industry 4.0 initiatives implementation. The following barrier that was the third most impactful was "Funding and Investment", like the first most impactful challenge, organisations are resistant to invest in industry 4.0 initiatives leading to a lack of software and hardware for their employees to use in line with industry 4.0 initiatives. The fourth most impactful initiative is "resistance to change" which mainly originates from the different parties within the organisations being unwilling to change as they are familiar with the traditional practices and may be fearful of new ways of working. The fifth and sixth most impactful challenges which were quantified as the same were "Knowledge and Understanding" and "Competency and Capabilities" This is due to the lack of knowledge within organisations and due to this lack of knowledge, employees do not have the capabilities and competency for industry 4.0 initiatives.

Objective 5: To investigate the key leading change strategies that have been adopted in the UK infrastructure sector to embrace Industry 4.0 concepts.

Research Question 8: What are the key change management strategies being implemented within organisations in the infrastructure sector to manage Industry 4.0 agenda issues?

This research study has revealed that there are four main key change management strategies organisations in the UK infrastructure sector have adopted to manage the change introduced by Industry 4.0 initiatives. The changes include People, Tools/Technologies, Strategies and Processes. These change strategies are vital for higher management and leaders within organisations for instance, people will require management of change due to industry 4.0 initiatives introducing processes which involve most employees within the organisation. Additionally, new roles will be introduced where organisations will have to employ new staff to fill those roles for a successful implementation. Furthermore, industry 4.0 involves tools and technology as the concept of industry 4.0 is the digitisation and automation of the sector, hence tools and technologies being used in organisations must be adjusted to work with the new processes. Organisations have implemented digital strategies within the next change management initiatives, this establishes a set plan of action for the entire organisation on the implementation of these initiatives. Finally, processes, industry 4.0 changes traditional processes within organisations to more efficient and productive processes, if these processes are not changed in line with the initiatives, the implementation will most likely fail, hence a clear understanding of the new processes that are introduced for initiatives can ensure a successful implementation.

Objective 6: To explore the potential benefits of adopting Industry 4.0 strategies in the infrastructure sector.

Research Question 9: What are the efforts that Industry 4.0 agenda has contributed to organisations within the infrastructure sector?

This study has explored the value that industry 4.0 initiatives implementation provides to an organisation within the UK infrastructure sector. The values were assessed with the triple bottom line approach, exploring the social, economic, and environmental dimensions. Infrastructure is a social sector as all infrastructure is for the community and the customers of the asset are the people of the community. During construction, the community and stakeholders are also key members as there can be disruptions, industry 4.0 initiatives can improve stakeholder relationships through connectivity. Additionally, the nature of infrastructure construction tends to impact the environment, using industry 4.0 initiatives improve environmental performance as environmentally friendly solutions can be adopted and reduction of waste and emission can be possible by using the initiatives to plan on better practices. Finally, the economic value provided by Industry 4.0 initiatives can allow organisations to have innovative business models while improving their competitiveness within the sector, hence the implementation of Industry 4.0 initiatives can be seen as a profitable action by organisations.

Objective 7: To develop and evaluate the Industry 4.0 business model framework.

Research Question 10: Is there a need for developing an innovative business model for adopting Industry 4.0 agenda within the infrastructure sector?

This study has developed and evaluated an integrated business model framework for the implementation of industry 4.0 initiatives in the UK infrastructure sector. The framework that has been developed is aimed to assist organisations within the infrastructure sector implement these initiatives and for those that have already implemented initiatives to better their processes to gain more value. The framework produced assists higher management and decision-makers within the organisation to understand the concept of Industry 4.0 and aid in the implementation and management of these strategies. The framework has been categorised into four key stages which are: inputs, processes, outputs, and outcomes, where the input stage allows organisations to understand the drivers of the initiative's implementations. The processes stage allows an understanding of the changes and challenges that are potentially faced. The output stage demonstrates the value of these initiatives that can be gained by organisations and the impact of these values on the organisation is shown in the outcomes stage.

An industry 4.0 readiness tool to assess the readiness of organisations in implementing industry 4.0 initiatives has been developed and evaluated. The goal of developing the tool was to support organisations in evaluating their readiness to implement industry 4.0 strategies and ensure successful implementation. The readiness tool considers the findings from this study and covers aspects including change, processes, individual aspects, and organisation level aspects. The development of the Industry 4.0 readiness tool can support higher management and decision-makers in recognizing what their organisation is lacking to ensure the successful implementation of Industry 4.0 initiatives.

11.4. RECOMMENDATIONS FOR THE INDUSTRY AND POLICYMAKERS

- The UK Government and policymakers should include the UK infrastructure sector when creating industry 4.0-related laws and regulations to allow the progress of general and valuable policies.
- The Government and policymakers should generate a straightforward framework to increase the UK infrastructure sectors leading power, this will allow them to generate a compensation force towards the UK infrastructure sector.
- The UK infrastructure sector should create a network where local communities and organisations within the sector can gain trust and understanding.
- Organisations within the UK infrastructure sector should involve stakeholders within the decision-making process, these include employees, members of the community, suppliers, and representatives of customers, this could create a major impact on industry 4.0 strategies adoption.
- The UK Government and policymakers should create audits on organisations since the BIM mandate and ensure standards are being met and implemented in the right way across the sector. In addition, creating standards for more Industry 4.0 agenda like the

BIM mandate can push organisations in the sector to implement more Industry 4.0 digital and automated processes.

- The UK infrastructure sector should review their projects and organisations' level of implementation of not only BIM Level 2 mandated standards but also industry 4.0 agenda such as AI which can advance the sector which can lead to a boost of economy changing the UK infrastructure sectors status.
- The large organisations in the sector have a medium to high level of implementation while small to medium size organisations have a low level of implementation, this shows that there is a substantial gap in knowledge within the sector. There is a need for knowledge to be shared within the sector sharing lessons learnt and best practices from organisations at an essential high level.
- Organisations within the UK infrastructure sector should push to raise awareness both up and down the chain within their staff to ensure that all staff are capable and consider investment in necessary resources to implement Industry 4.0 agenda successfully. Organisations should create digital strategies and if already created then enhance their digital strategy to a greater level.
- Technology is advancing every year, hence there should be continuous upskilling for all employees throughout the organisation. In addition, software and technologies invested in are to be kept up to date to keep up with newer capabilities that can positively impact the organisation.
- Organisations within the infrastructure sector should ensure that their staff are upskilled and trained to increase competency throughout the organisation, especially from higher levels of management, this will allow the competencies and capability of the organisation to be in line with the new procedures.
- To achieve a full and successful implementation of Industry 4.0 agenda, there is a need for the technologies and right tools to be made available. This will support the staff as they train to enhance their skills and competencies while using the available tools and technologies.
- Organisations should ensure they have a strategy in place this allows readiness and acceptance from a higher level of management within the organisation creating a set plan of innovative procedures and what problems and challenges they can resolve through the adoption of Industry 4.0 agenda. This allows staff to visualise the vision of adopting Industry 4.0 agenda creating a vision for the entire organisation.

- Organisations and leaders within the sector should ensure that the new processes are spread across all members within the organisation which can benefit the transitions stage to the fourth industrial revolution, in addition, organisations should contemplate changes in the work environment due to Industry 4.0 agenda and ensure communication to staff is clear and there is transparency within the organisation.
- Comprehension Policy: The UK Government should create and implement policies and frameworks for Industry 4.0 agenda which should be communicated in an understandable way to allow organisations within the sector a deep understanding of how to successfully implement Industry 4.0 agenda.
- Commitment: Industry 4.0-based knowledge and capabilities are and will be in the future a huge challenge within the infrastructure sector as the more time goes the more technology is advancing, therefore industry 4.0 agenda processes and standards training programmes related to the management of industry 4.0 agenda will allow higher management within organisations to change their mindset and gain a better understanding on how to successfully implement these processes.
- Competence: The UK Government should develop knowledge-based strategies as it is of great importance to developing an understanding of the fourth industrial revolution and the new processes introduced. This can allow the younger generation to gain knowledge on new ways of working and allow their culture to become solidified.
- Culture: Organisations within the sector should change their attitudes towards a positive and open-to-learning approach to encourage better interaction throughout the organisation thus encouraging a successful implementation of Industry 4,0 agenda. Industry 4.0 agenda should gradually be incorporated throughout the teams within the organisation from the management level including Human Resources, Administrators, Site Engineers, Commercial, Subcontractors, Agents, Planning team, Surveyors, Logistics, design, Stakeholders and Operations.
- Capabilities: Businesses have adopted many Industry 4.0 agendas across the economy, to improve the infrastructure sector's position in the fourth industrial revolution, organisations need to consider their level of capabilities and competency
  for the fourth industrial revolution. Organisations need to avoid traditional practices and recruit more competent skilled staff who can also share knowledge with staff already within the organisation.
- Collaborative Leadership: The development of digital and innovation strategies can be challenging and complicated as risks and issues, be they short-term or long-term, should

be considered. These considerations should also include stakeholders to allow the collaboration of all parties. Consequently, a consistent approach throughout the senior leadership and management of the parties involved is a necessity for a successful implementation of Industry 4.0 agenda within the UK Infrastructure sector.

- *O*rganisations within the infrastructure sector should ensure that industry 4.0 knowledge is shared throughout the organisation allowing enhance collaboration and knowledge sharing through all parties.
- Higher management within organisations should integrate and incorporate industry 4.0 agenda and technologies within their processes and gain a competitive advantage, this will require the upskilling of staff, however over time this will generate a positive impact on processes and efficiency.

11.5. CONTRIBUTION TO KNOWLEDGE

This study contributes knowledge to the UK infrastructure sector and its supply chain which includes each level such as higher management, staff, policymakers, and the decision makers within organisations in the sector. The results will:

- Enhance knowledge and understanding within organisations of industry 4.0 concepts and innovation.
- Enhance the understanding of key drivers that pressure the UK infrastructure sector to implement industry 4.0 initiatives which can enable the higher management in organisations to understand the key drivers more leading to opportunities for efficient implementation and adoption.
- Aid the senior managers in organisations in the sector in building a plan of action for the adoption of Industry 4.0 initiatives.
- Enable change management strategies understanding for decision-makers in organisations for implementing Industry 4,0 initiatives (.
- Allow organisations in the UK infrastructure sector to become more aware of the challenges barricading the implementation of Industry 4.0 initiatives.
- Allow organisations in the UK infrastructure sector to be enabled to assess their position and capabilities for the adoption of the initiatives with the use of the readiness tool and GTMA analysis.
- Increase knowledge on how Industry 4.0 initiatives impact social, environmental, and economic performance and their relationships with the initiatives.

- Guide senior leaders with the use of the framework developed to allow a better understanding of Industry 4.0 concepts while assisting the implementation, management, and control of these strategies and measuring performance.

11.6. FUTURE RECOMMENDATIONS

This study has provided valuable insight into key areas, however further research can be conducted with further development on the topic of research:

1. This study presents results from qualitative data gathered from 21 experts from thirteen different organisations. It would be of use to further the range of contributors gathering quantitative data as this can allow a comparison between the results from this study and further development.
2. This study presents the impact and significance of industry 4.0 initiatives development in the UK infrastructure sector. Consequently, future research can develop a measurement of Industry 4.0 within the UK infrastructure sector as measuring the success or failure of Industry 4.0 within the industry has proven to be a crucial part of Industry 4.0 implementation.
3. This study uses an exploratory nature which means that it is limited in the findings presented as the findings are not generalised, future research could get deeper using a different research design and provide better expression. Additionally, the research accounts for the infrastructure sector in general, this can be further split into the different industries within the sector for better clarification.

REFERENCES

Jian et. al, 2014. A Project-Based Quantification of BIM Benefits. *International Journal of Advanced Robotic Systems.*

A.G. Frank, L. D. N. A., 2019. Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics,* pp. 15-26.

Abdul-Hamid, A.-Q.et al., 2020. Impeding challenges on industry 4.0 in circular economy: Palm oil industry in Malaysia. *Computers and Operations Research.*

Adetunji, I., Price, A., Fleming, P. and Kemp, P., 2003. Sustainability and the UK construction industry—a review. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability,* pp. 185-199.

Adhabi, E. and Anozie, C. B., 2017. Literature Review for the Type of Interview in Qualitative Research. *International Journal of Education,* pp. 1-12.

Adolph, S., Tisch, M. and Metternich, J., 2014. CHALLENGES AND APPROACHES TO COMPETENCY DEVELOPMENT FOR FUTURE PRODUCTION. *Journal of International Scientific Publications.*

Agrawal, S., Singh, R. K. and Murtaza, Q., 2016. Disposition decisions in reverse logistics: Graph theory and matrix approach. *Journal of Cleaner Production,* pp. 93-104.

Aguilar-Rodríguez, I. E. et al., 2021. Relationship between social culture, industry 4.0, and organizational performance in the context of emerging economies. *Journal of Industrial Engineering and Management,* pp. 750-770.

Ahuja, R. et al., 2020. Factors influencing BIM adoption in emerging markets - the case of India. *International journal of construction management,* pp. 65-76.

Akbar, M. A., Sang, J., Khan, A. A. and Hussain, S., 2019. Investigation of the requirements change management challenges in the domain of global software development. *Journal of Software: Evolution and Process.*

Alaloul, W. S., Liew, M., Zawawi, N. A. W. A. and Kennedy, I. B., 2020. Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders. *Ain Shams Engineering Journal,* 11(1), pp. 225-230.

Albort-Morant, G., Leal-Rodríguez, A. L. and De Marchi, V., 2018. Absorptive capacity and relationship learning mechanisms as complementary drivers of green innovation performance. *Journal of Knowledge Management,* pp. 432-452.

Alreshidi, E., Mourshed, M. and Rezgui, Y., 2017. Factors for effective BIM governance. *Journal of Building Engineering,* pp. 89-101.

Alshenqeeti, H., 2014. Interviewing as a Data Collection Method: A Critical Review. *Sciedu Press.*

Ana Karina Silverio Rodriguez, 2020. *Implementation of building information modelling in the Dominican Republic construction industry,* s.l.: University of Wolverhampton.

Ancarani, A., Mauro, C. D. and Mascali, F., 2019. Backshoring strategy and the adoption of Industry 4.0: Evidence from Europe. *Journal of World Business,* pp. 360-371.

Antonova, A., Gourova, D. E. and Nikolov, D. R., 2006. REVIEW OF TECHNOLOGY SOLUTIONS FOR KNOWLEDGE MANAGEMENT. *2nd IET International Conference on Intelligent Environments,* pp. 39-44.

Antunes, J. G., Pinto, A., Reis, P. and Henriques, C., 2018. INDUSTRY 4.0: A CHALLENGE OF COMPETITION. *ENGINEERING, TECHNOLOGY, MANAGEMENT AND TOURISM,* pp. 89-97.

Aripin, I. D. M., Zawawi, E. M. A. and Ismail, a. Z., 2019. Factors Influencing the Implementation of Technologies Behind Industry 4.0 in the Malaysian Construction Industry. *EDP Sciences.*

Asah-Kissiedu, M. et al., 2021. An Integrated Safety, Health and Environmental Management Capability Maturity Model for Construction Organisations: A Case Study in Ghana. *Buildings* .

ASQ, 2022. *WHAT IS CHANGE MANAGEMENT?.* [Online]
Available at: https://asq.org/quality-resources/change-management

Awuzie, B. and Mcdermott, P., 2017. An abductive approach to qualitative built environment research: A viable system methodological exposé. *Qualitative Research Journal,* pp. 356-372.

Babbie, E. R., 2010. *The Practice of Social Research.* London: SAGE Publications.

Bag, S., Dhamija, P., Bryde, D. J. and Singh, R. K., 2022. Effect of eco-innovation on green supply chain management, circular economy capability, and performance of small and medium enterprises. *Journal of Business Research,* pp. 60-72.

Bahrin, M., Othman, M., Azli, N. and Talib, M., 2016. Industry 4.0: a review on industrial automation and robotic. *Jurnal Teknologi,* pp. 137-143.

Bai, C., Dallasega, P., Orzes, G. and Sarkis, J., 2020. Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics,* Volume 229.

Bank of England, 2020. *How has growth changed over time?.* [Online]
Available at: https://www.bankofengland.co.uk/knowledgebank/how-has-growth-changed-over-time

Barge-Gil, A. and Modrego, A., 2011. The impact of research and technology organizations on firm competitiveness. Measurement and determinants. *J Technol Transf.*

Barney, J., 1991. Firm resources and sustained competitive advantage. *J manage,* pp. 99-120.

Barney, J. and Hesterly, W., 2007. *Strategic Management and Competitive Advantage.* Englewood Cliffs NJ: Prentice hall.

Basir, W. N. F. W. A., Majid, Z., Ujang, U. and Ujang, U., 2018. INTEGRATION OF GIS AND BIM TECHNIQUES IN CONSTRUCTION PROJECT MANAGEMENT – A REVIEW. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* pp. 307-316.

Basir, W. N. F. W. A. et al., 2020. THE INTEGRATION OF BIM AND GIS IN CONSTRUCTION PROJECT – A DATA CONSISTENCY REVIEW. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*

Bature, A., Melville, L., Rahman, K. M. and Aulak, P., 2022. Microalgae as feed ingredients and a potential source of competitive advantage in livestock production: A review. *Livestock Science.*

Baz, J. E. and Laguir, I., 2017. Third-party logistics providers (TPLs) and environmental sustainability practices in developing countries. *International Journal of Operations and Production Management,* pp. 1451-1474.

BBC, 2019. *How ICT has changed communication and collaboration.* [Online]
Available at: https://www.bbc.com/bitesize/guides/zg6g87h/revision/1

Benjaminsson, F., Kronholm, T. and Erlandsson, E., 2019. A framework for characterizing business models applied by forestry service contractors. *Scandinavian journal of forest research,* pp. 779-788.

Berrone, P., Fosfuri, A., Gelabert, L. and Gomez-Mejia, L. R., 2012. Necessity as the mother of 'green' inventions: Institutional pressures and environmental innovations. *Strategic Management Journal,* pp. 891-909.

Bienhaus, F. and Haddud, A., 2018. Procurement 4.0: factors influencing the digitisation of procurement and supply chains. *Business Process Management Journal,* pp. 965-984.

Bilberg, A. and Malik, A. A., 2019. Digital twin driven human–robot collaborative assembly. *CIRP Annals,* pp. 499-502.

Bilgen, H., 2021. A global comparison methodology to determine critical requirements for achieving industry 4.0. *Technological Forecasting and Social Change.*

Birkel, H. and M.Müller, J., 2021. Potentials of industry 4.0 for supply chain management within the triple bottom line of sustainability – A systematic literature review. *Journal of Cleaner Production.*

Birkel, H. et al., 2019. Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers. *Sustainability (Switzerland).*

Borioli, S., 2017. *The Minimum Viable Organization Model: a grounded model of planned rioli, S.G; (2017) The Minimum Viable Organization Model: a grounded model of planned ,* London: University College London.

Borrego, M. and Henderson, a. C., 2014. Increasing the Use of Evidence-Based Teaching in STEM Higher Education: A Comparison of Eight Change Strategies.. *Journal of Engineering Education ,* pp. 220-252.

Bosman, L., Hartman, N. and Sutherland, J., 2020. How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies. *Journal of Manufacturing Technology Management,* pp. 1117 - 1141.

Braccini, A. M. and Margherita, E. G., 2019. Exploring Organizational Sustainability of Industry 4.0 under the Triple Bottom Line: The Case of a Manufacturing Company. *Sustainability.*

Braun, V. and Clarke, V., 2016. (Mis) Conceptualising themes, thematic analysis, and other problems with Fugard and Potts' (2015) sample-size tool for thematic analysis. *International Journal of social research methodology,* pp. 739-743.

Bresser, R. K. F. and Powalla, C., 2012. Practical implications of the resource-based view: Assessing the predictive power of the VRIO-framework. *Zeitschrift für Betriebswirtschaft,* pp. 335-359.

Broussard, M., 2018. *Artificial Unintelligence How Computers Misunderstand the World.* Philadelphia: Harper's.

Brown, D. R., Rose, D. and Gordon, R., 2016. De-commoditizing change management. *Journal of Organizational Change Management,* pp. 793-803.

Brown, G. and Weber, D., 2012. Measuring change in place values using public participation GIS (PPGIS). *Applied Geography,* pp. 316-324.

Brozzi, R., Forti, D., Rauch, E. and Matt, D. T., 2020. The Advantages of Industry 4.0 Applications for Sustainability: Results from a Sample of Manufacturing Companies. *Sustainability.*

Bülent, A., Kittisak, J., Muhammad, A. M. and Yesim, K., 2021. *Emerging Trends in and Strategies for Industry 4.0 During and Beyond Covid-19.* Berlin/Boston: De Gruyter.

Cahaya, F. R., Porter, S., Tower, G. and Brown, A., 2015. The Indonesian Government's coercive pressure on labour disclosures: Conflicting interests or government ambivalence?. *Sustainability accounting, management and policy journal,* pp. 475-497.

Cai, W.-g. and Zhou, X.-l., 2014. On the drivers of eco-innovation: empirical evidence from China. *Journal of Cleaner Production,* pp. 239-248.

Cambridge Dictionary, 2019. *Meaning of Infrastructure.* [Online]
Available at: https://dictionary.cambridge.org/dictionary/english/infrastructure

Cambridge University Press, 2019. *Infrastructure.* [Online]
Available at: https://dictionary.cambridge.org/us/dictionary/english/infrastructure

Cardeal, N. and Antonio, N., 2012. Valuable, rare, inimitable resources and organization (VRIO) resources or valuable, rare, inimitable resources (VRI) capabilities: what leads to competitive advantage?. *Afric. J. Bus. Manag,* pp. 10159 - 10170.

Carlin, E. M., 2010. *Construction Law Signal.* [Online]
Available at: http://www.constructionlawsignal.com/by-subject/design-and-technology/the-legalrisks-of-building-information-modeling-bim/ [Accessed 08 November 2015].

Castelo-Branco, I., Cruz-Jesus, F. and Oliveira, T., 2019. Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry,* pp. 22-32.

Castelo-Branco, I., Cruz-Jesus, F. and Oliveira, T., 2019. Assessing Industry 4.0 readiness iin manufacturing: Evidence for the European Union. *Computers in Industry,* pp. 22-32.

Chappine, P., 2003. *New Innovations.* [Online]
Available at: https://study.com/academy/lesson/the-second-industrial-revolution-timelineinventions.html

Chatzoglou, P., Chatzoudes, D., Sarigiannidis, L. and Theriou, G., 2018. The role of firm-specific factors in the strategy-performance relationship: Revisiting the resource-based view of the firm and the VRIO framework. *Management Research Review,* pp. 46-73.

Cheng, J. C. P., Tan, Y., Song, Y. and Wang, X., 2017. A semi-automated approach to generate 4D/5D BIM models for evaluating different offshore oil and gas platform offshore oil and gas platform. *Visualization in Engineering.*

Chen, H.-L., 2021. Impact of Industry 4.0 on Corporate Financial Performance: A Moderated Mediation Model. *Sustainability.*

Chen, X., Chen, L., Jiang, M. and Yan, J., 2021. Does RandD intensity promote the adoption of circular supply chain management? Evidence from China. *Industrial Marketing Management,* pp. 153-166.

Chen, X., Yi, N., Zhang, L. and Li, D., 2018. Does institutional pressure foster corporate green innovation? Evidence from China's top 100 companies. *Journal of cleaner production,* pp. 304-311.

Ching, K. V., 2019. A Case Study of Return on Investment for Multi-sites Test Handler in The Semiconductor Industry Through Theory of Industry 4.0 ROI Relativity. *International Journal of Recent Contributions from Engineering, Science and IT (iJES).*

Chmielewska, M., Stokwiszewski, J., Markowska, J. and Hermanowsk, T., 2022. Evaluating Organizational Performance of Public Hospitals using the McKinsey 7-S Framework. *BMC Health Services Research.*

Ciabuschi, F., Dellestrand, H. and Martín, O. M., 2011. Internal Embeddedness, Headquarters Involvement, and Innovation Importance in Multinational Enterprises. *Journal of Management Studies,* pp. 1612-1639.

Ciliberti, S., Carraresi, L. and Bröring, S., 2016. Drivers of innovation in Italy: food versus pharmaceutical industry. *British Food Journal,* pp. 1292-1316.

CITB, 2017. *UK Industry Performance Report,* London: CITB.

Cole, C. and Chase, S., 2011. Research Methodologies and Professional Practice: Considerations and Practicalities. *The Electronic Journal of Business Research Methods,* pp. 141-151.

Cone, C. and Unni, E., 2020. Achieving consensus using a modified Delphi Technique embedded in Lewin's change management model designed to improve faculty satisfaction in a pharmacy school. *Research in Social and Administrative Pharmacy,* pp. 1711-1717.

Connelly, M., 2020. *The Kurt Lewin Change Management Model.* [Online] Available at: https://www.change-management-coach.com/kurt_lewin.html Coppin, B., 2004. Artificial Intelligence Illuminated. *Research Gate.*

Cowley-Cunningham, M. B., 2017. Online Business Review of Susskind, R., and Susskind, D. (2015). The Future of the Professions: How Technology will Transform the Work of Human Experts – Oxford University Press, UK.. *AB Marketing.*

Craven, J., 2015. *What is infrastructure? why is it impotant?.* [Online]
Available at: http://architecture.about.com/od/engineeringconstruction/g/infrastructure.htm [Accessed 03 November 2015].

Creswell, J. W., 2007. *Qualitative Inquiry and Research Design: choosing among five approaches.* Lincoln: SAGE Publications.

Cruz-Cázares, C. et al., 2018. Public funds and internal innovation goals as drivers of formal and informal open innovation practices: A European regional comparison. *Management Research,* pp. 159-178.

Cunha, T. P., Mexas, M. P., Silva, A. C. d. and Quelhas, O. L. G., 2020. Proposal guidelines to implement the concepts of industry 4.0 into information technology companies. *TQM Journal.*

Dangelico, R. M. and Pujari, D., 2010. Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability. *Journal of Business Ethics,* pp. 471-486.

Daniotti, B., Gianinetto, M. and Torre, S. D., 2020. *Digital Transformation of the Design, Construction and Management Processes of the Built Environment.* s.l.:Cham: Springer International Publishing.

Dawood, I. and Underwood, J., 2010. Research Methodology Explained. *PM-05 - Advancing Project Management for the 21st Century .*

Dawson, R., 2015. *A Climate Change Report Card for Infrastructure LWEC Report Card,* London: Living with Environmental Change.

Dede, T., Kankal, M. and Vosoughi, A. R., 2019. Artificial Intelligence Applications in Civil Engineering. *Advance in Civil Engineering,* pp. 3-5.

DeGracia, D. J., Anggraini, F. T., Taha, D. T. M. and Huang, Z.-F., 2014. Inductive and Deductive Approaches to Acute Cell Injury. *International Scholarly Research Notices.*

Department for Business Innovatin and Skill, 2013. *UK Construction; An economic analysis of the sector,* London: Crown Copyright.

DePietro, R., Wiarda, E. and Fleischer, M., 1990. *The context for change: organisation, technology and environment, in: L.G. Tornatzky, M. Fleischer (Eds.).* Lexington: Lexington Books.

Diaz, P., 2016. Analysis of Benefits, Advantages and Challenges of Building Information Modelling in Construction Industry. *Journal of Advances in Civil Engineering,* pp. 1-11.

DiCicco-Bloom, B. and Crabtree, B. F., 2006. The qualitative research interview. *Medical Education,* pp. 314-321.

Dinter, R. v., Tekinerdogan, B. and Catal, C., 2021. Automation of systematic literature reviews: A systematic literature review. *Information and Software Technology.*

Dionisio, M., 2021. *The Impact of COVID-19: a Major Crisis or Just Another One?.* Rio de Janerio: Coppead.

Dowhower, J. F., 2010. *Utilizing BIM for Sustainable Architecture.* [Online]
Available at: https://jdowhower.wordpress.com/chapter-5-summary-conclusions/bim-impacts-onstakeholder-collaboration-workflows/ [Accessed 26 November 2015].

Durand, R., Hawn, O. and Ioannou, I., 2019. Willing and Able: A General Model of Organizational Responses to Normative Pressures. *Academy of Management Review,* pp. 299-320.

Dzhengiz, T. and Niesten, E., 2020. Competences for Environmental Sustainability: A Systematic Review on the Impact of Absorptive Capacity and Capabilities. *Journal of Business Ethics ,* pp. 881906.

Eadie, R., Perera, S., Heaney, G. and Carlisle, J., 2007. DRIVERS AND BARRIERS TO PUBLIC SECTOR E-PROCUREMENT WITHIN NORTHERN IRELAND'S CONSTRUCTION INDUSTRY. *itcon.*

Eastman, C., 2011. *BIM Handbook.* second ed. New Jersey: John Wiley and Sons.

Egan, J., 1998. *Rethinking Construction,* London: The Construction Task Force.

Egan, J., 1998. *RETHINKING CONSTRUCTION.* London: Crown Copyright.

Eldik, M. A. v. et al., 2020. BIM-based environmental impact assessment for infrastructure design projects. *Automation in Construction.*

Elkington, J., 1998. Cannibals with Forks: The Triple Bottom Line of 21st Century Business. *New Society Publishers.*

Emerson, R. W., 2015. Convenience Sampling, Random Sampling, and Snowball Sampling: How Does Sampling Affect the Validity of Research?. *Journal of visual impairment and blindness,* pp. 164168.

Erboz, G., 2017. How To Define Industry 4.0: Main Pillars Of Industry 4.0. *Conference: Managerial trends in the development of enterprises in globalization era..*

Erol, S. et al., 2016. Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production. *Procedia CIRP,* pp. 13-18.

Eslami, M. H. et al., 2021. Financial performance and supply chain dynamic capabilities: the Moderating Role of Industry 4.0 technologies. *International Journal of Production Research.*

ETTAIBI, M. and Bouchaib, M., 2021. Integrative Digital Transformation and Organizational Competitiveness(OC) : Proposal for a Transition Strategy to the Aeronautics Industry 4.0 (TSAI) based on a Knowledge Management(KM) approach in a Moroccan ecosystem environment.. *VIGISAN.*

Eurydice Fotopoulou, 2022. *Infrastructure in the UK, investment and net stocks: May 2022.* [Online] Available at: https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/articles/developingnewmeasuresofinfrastructureinvestment/may2022 [Accessed 27 04 2023].

Evans, D. and Popova, A., 2016. How systematic is that systematic review? The case of improving learning outcomes. *Campbell Collaboration.*

EvaristoJiménez-Contreras, Anegón, F. M. and López-Cózar, E. D., 2003. The evolution of research activity in Spain: The impact of the National Commission for the Evaluation of Research Activity (CNEAI). *Research Policy,* pp. 123-142.

Eyel, C. Ş. and Mete, İ., 2021. Investigating User Resistance of Employees Working at Technology Companies in Istanbul towards Digital Transformation. *International journal of information science and management,* p. 93.

Fareri, S. et al., 2020. Estimating Industry 4.0 impact on job profiles and skills using text mining. *Computers in industry.*

Finger, M. and Montero, J., 2023. Digitalizing infrastructure, digital platforms and public services. *SAGE Journals,* 24(1).

Fitzgerald, M., Kruschwitz, N., Bonnet, D. and Welch, M., 2013. *Embracing Digital Technology,* Massachusetts : Massachusetts Institute of Technology.

Florescu, A. and Barabas, S., 2022. Development Trends of Production Systems through the Integration of Lean Management and Industry 4.0. *Industrial Management and Engineering in the Fourth Industrial Revolution.*

Flores, E., Xu, X. and Lu, Y., 2019. Human Capital 4.0: a workforce competence typology for Industry 4.0. *emerald.*

Floros, G. S., Ruff, P. and Ellul, C., 2020. IMPACT OF INFORMATION MANAGEMENT DURING DESIGN and CONSTRUCTION ON DOWNSTREAM BIM-GIS INTEROPERABILITY FOR RAIL INFRASTRUCTURE. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*

Fogaça, D., Grijalvo, M. and Sacomano Neto, M., 2022. An institutional perspective in the industry 4.0 scenario: A systematic literature review. *Journal of industrial engineering and management,* pp. 309322.

Fragapane, G. et al., 2022. Increasing flexibility and productivity in Industry 4.0 production networks with autonomous mobile robots and smart intralogistics. *ARTIFICIAL INTELLIGENCE IN OPERATIONS MANAGEMENT,* pp. 125-143.

Franceschi, A. D., 2022. Building the New Infrastructure for the Digital Economy: A Global Challenge. *GRUR International,* 71(10), pp. 907-908.

Frederico, G. F., Garza-Reyes, J. A., Kumar, A. and Kumar, V., 2021. Performance measurement for supply chains in the Industry 4.0 era: a balanced scorecard approach. *International journal of productivity and performance management,* pp. 789-807.

Fuenfschilling, L. and Truffer, B., 2014. The structuration of socio-technical regimes—Conceptual foundations from institutional theory. *Research policy,* pp. 772-791.

Furrer, F., Novkovic, T. and Siegwart, R., 2023. Modelify: An approach to incrementally build 3D object models for map completion. *The International Journal of Robotics Research.*

Gadekar, R., Sarkar, B. and Gadekar, A., 2022. Investigating the relationship among Industry 4.0 drivers, adoption, risks reduction, and sustainable organizational performance in manufacturing industries: An empirical study. *Sustainable Production and Consumption,* pp. 670-692.

Gajdzik, B., Grabowska, S. and Saniuk, S., 2021. A Theoretical Framework for Industry 4.0 and Its Implementation with Selected Practical Schedules. *Energies (Basel),* p. 940.

Galli, B. J., 2019. Comparison of Change Management Models: Similarities, Differences, and Which Is Most Effective?. *RandD Management in the Knowledge Era,* pp. 605-624.

Ghadimi, P. et al., 2022. The successful implementation of industry 4.0 in manufacturing: An analysis and prioritization of risks in Irish industry. *Technological Forecasting and Social Change.*

Ghadimi, P., Wang, C., Lim, M. K. and Heavey, C., 2019. Intelligent sustainable supplier selection using multi-agent technology: Theory and application for Industry 4.0 supply chains. *Computers and Industrial Engineering,* pp. 588-600.

Ghobakhloo, M., 2018. The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management,* pp. 1-27.

Ghosh, A., Chakraborty, D. and Law, A., 2018. Artificial intelligence in Internet of things. *CAAI Transactions on Intelligence Technology,* pp. 208-218.

Gledson, B. J. and Greenwood, D., 2017. The adoption of 4D BIM in UK construction industry: an innovation diffusion approach. *Engineering, construction, and architectural management,* pp. 950967.

Golan, M., Cohen, Y. and Singer, G., 2020. A framework for operator – workstation interaction in Industry 4.0. *International Journal of Production Research.*

González-Santander, P. D. M. and Lemus-Aguilar, I., 2021. Current Innovation Sources Driving The Spanish Electric Power Sector. *Ingeniería e investigación.*

Gopalakrishnan, K. et al., 2012. Sustainable supply chain management: A case study of British Aerospace (BAe) systems. *International Journal of Production Economics,* pp. 193-203.

GOV.UK, 2022. *Transforming for a digital future: 2022 to 2025 roadmap for digital and data,* London: Central Digital and Data Office.

Habraken, M. and Bondarouk, T., 2020. Embracing Variety in Decision-Making Regarding Adoption of Industry 4.0. *Department of Human Resource Management, Faculty of Behavioural, Management and Social Sciences.*

Hamdo, S. S., 2021. Change Management Models: A Comparative Review. *Department of Business Administration Institute of Social Sciences Istanbul Okan University Turkey.*

Hasle, P., Limborg, H. J. and Nielsen, K. T., 2014. Working environment interventions – Bridging the gap between policy instruments and practice. *Safety Science,* pp. 73-80.

Henke, I., Cartenì, A., Molitierno, C. and Errico, A., 2020. Decision-Making in the Transport Sector: A Sustainable Evaluation Method for Road Infrastructure. *Sustainable Mobility: Social, Technological and Environmental Issues.*

Hennink, M. and Kaiser, B. N., 2022. Sample sizes for saturation in qualitative research: A systematic review of empirical tests. *Social Science and Medicine,* Volume 292.

Heron, j. and Reason, P., 1997. A Participatory Inquiry Paradigm.. *Qualitative Inquiry,* pp. 274-294.

History.com, 2020. *Industrial Revolution.* [Online]
Available at: https://www.history.com/topics/industrial-revolution/industrial-revolution HM Government, 2012. *Building Information Modelling,* London: Crown Copyright.
HM Government, 2021. *Net Zero Strategy: Build Back Greener,* London: Crown Copyright.

HM Treasury and Cabinet Office, 2016. *National Infrastructure Delivery Plan 2016–2021,* London: Crown Copyright.

HM Treasury, 2013. *National Infrastructure Plan 2013.* [Online] Available at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263159/national_infrastructure_plan_2013.pdf
[Accessed 04 November 2015].

HM Treasury, 2014. *Investing in UK Infrastructure,* London: UK Trade and Investment.

HM Treasury, 2022. *Policy paper; The Growth Plan 2022,* London: HM treasury.

Hoeschl, H. C. and Barcellos, V., 2006. ARTIFICIAL INTELLIGENCE AND. *Juridical Intelligence and Systems - IJURIS,* pp. 11-19.

Hofmann, E. and Rüsch, M., 2017. Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry,* pp. 23-34.

Hopkins, J. L., 2021. An investigation into emerging industry 4.0 technologies as drivers of supply chain innovation in Australia. *Elsevier Computers in Industry.*

Hori, Y. and Ogawa, T., 2017. VISUALIZATION OF THE CONSTRUCTION OF ANCIENT ROMAN BUILDINGS IN OSTIA USING POINT CLOUD DATA. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*

Horvath, D. and Szabo, R. Z., 2019. Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?. *Technological forecasting and social change,* pp. 119-132.

Horváth, D. and Szabó, R. Z., 2019. Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?. *Technological Forecasting and Social Change,* pp. 119-132.

House of Commons Committee of Public Accounts, 2021. *Lessons learned from Delivery of Major Infrastructure Projects,* London: House of Commons Committee of Public Accounts.

Hovarth, D. and Szabo, R. Z., 2019. Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?. *Technological Forecasting and Social Change,* pp. 19-132.

HUNT, S. D. and DAVIS, D. F., 2008. GROUNDING SUPPLY CHAIN MANAGEMENT IN RESOURCE-ADVANTAGE THEORY. *Journal of supply chain management.*

Hunt, S. D. and Davis, D. F., 2012. GROUNDING SUPPLY CHAIN MANAGEMENT IN RESOURCE-ADVANTAGE THEORY: IN DEFENSE OF A RESOURCE-BASED VIEW OF THE FIRM. *Journal of Supply Chain Management,* pp. 14-20.

Hurtado, K. and Sullivan, K., 2012. How to measure the benefits of BIM - A case study approach. *Automation in Construction,* pp. 149-159.

Hussain, S. T. et al., 2018. Kurt Lewin's change model: A critical review of the role of leadership and employee involvement in organizational change. *Journal of Innovation and Knowledge,* 3(3), pp. 123127.

I.M. Cavalcantea, E. F. F. D. I., 2019. A supervised machine learning approach to data-driven simulation of resilient supplier selection in digital manufacturing. *International Journal of Information Management,* pp. 86-97.

ICE, 2015. *ICE Autumn Statement Submission,* London: ICE.

Infrastructure and Projects Authority, 2016. *Government Construction Strategy 2016-20,* s.l.: Infrastructure and Projects Authority.

Infrastructure and Projects Authority, 2021. *Policy paper; Transforming Infrastructre [erformance: Roadmap tp 2030,* London: Gov.UK.

Ito, A. et al., 2021. Dealing with resistance to the use of Industry 4.0 technologies in production disturbance management. *Journal of Manufacturing Technology Management,* 32(9).

Jackson, G., Strauss, D., Bernard, S. and Pearson, T., 2019. *The UK economy at a glance.* [Online] Available at: https://ig.ft.com/sites/numbers/economies/uk/

Jain, V. and Raj, T., 2016. Modeling and analysis of FMS performance variables by ISM, SEM and GTMA approach. *International Journal of Production Economics,* pp. 84-96.

Jakubczak, W., Gołębiowska, A. and Prokopowicz, D., 2021. The Legal and Security Aspects of ICT and Industry 4.0 Importance for Financial Industry 4.0 Development. *European Research Studies,* pp. 169-181.

Jallow, H., Renukappa, S. and Alneyadi, A., 2019. The Concept of Smart Motorways. *2019 3rd International Conference on Smart Grid and Smart Cities (ICSGSC),* pp. 18-21.

Jallow, H., Renukappa, S. and Suresh, S., 2020. Knowledge Management and Artificial Intelligence (AI). *European Conference on Knowledge Management,* pp. 363-369.

Jallow, H., Renukappa, S. and Suresh, S., 2020. Knowledge Management and Artificial Intelligence (AI). *European Conference on Knowledge Management,* pp. 363-369.

Jallow, H., Renukappa, S. and Suresh, S., 2021. The Impact of COVID-19 ourbreak on United Kingdom infrastructure sector. *Smart and sustainable built environment,* pp. 581-593.

Jallow, H., Renukappa, S. and Suresh, S., 2022. Artificial Intelligence and the UK Construction Industry – Empirical Study. *Taylor and Francis.*

Jallow, H., Renukappa, S., Suresh, S. and Algahtani, K., 2021. Managing COVID-19 Related Knowledge in the UK Infrastructure Sector. *European Conference on Knowledge Management,* pp. 371-380.

Jallow, H., Renukappa, S., Suresh, S. and Al-Meraikhi, H. S., 2022. Industry 4.0 application adoption and implementation in UK infrastructure sector: Change management strategies. *BAM2022* .

Jallow, H., Renukappa, S., Suresh, S. and Alneyadi, A., 2017. Building Information Model For Infrastructure: Challenges and Benefits. *The Ninth International Conference on Construction in the 21st Century (CITC-9).*

Jallow, H., Renukappa, S., Suresh, S. and Alneyadi, A., 2018. BIM for collaboration and coordination. *The Tenth International Conference on Construction in the 21st Century (CITC-10).*

Jallow, H., Renukappa, S., Suresh, S. and Alneyadi, A., 2019. IMPLEMENTATION OF BUILDING INFORMATION MODELLING IN THE UK INFRASTRUCTURE SECTOR – A CASE STUDY.

CIB, pp. 338-349.

Jallow, H., Renukappa, S., Suresh, S. and Alneyadi, A., 2019. Implementing a BIM collaborative Workflow in the UK infrastructure Sector. *Proceedings of the 2019 3rd International Conference on information system and data mining,* pp. 103-108.

Jallow, H., Renukappa, S., Suresh, S. and Alneyadi, A., 2019. Implementing a BIM Collaborative Workflow In The UK Infrastructure Sector. *Proceedings of the 2019 3rd International Conference on information system and data mining,* pp. 103-108.

Jallow, H., Renukappa, S., Suresh, S. and Alneyadi, A., 2020. Building Information Modelling in Transport Infrastructure Sector. *Collaboration and Integration in Construction, Engineering, Management and Technology ,* pp. 69-73.

Jallow, H., Renukappa, S., Suresh, S. and Neyadi, A. A., 2018. Managing Knowledge in A Building Information Modelling Context: A Case Study. *International Journal of Knowledge Engineering ,* pp. 36-42.

James, A. T. et al., 2022. Analysis of human resource management challenges in implementation of industry 4.0 in Indian automobile industry. *Technological Forecasting and Social Change.*

Jamshed, S., 2014. Qualitative research method-interviewing and observation. *Journal of Basic and Clinical Pharmacy,* pp. 87-88.

Javaid, M. et al., 2020. Industry 4.0 technologies and their applications in fighting COVID-19 Pandemic. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews,* pp. 419-422.

Jayashree, S., Reza, M. N. H., Malarvizhi, C. A. N. and Mohiuddin, M., 2021. Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms. *Heliyon.*

Jayawardena-Willis, T. S., Pio, E. and McGhee, P., 2019. The Divine States (brahmaviharas) in Managerial Ethical Decision-Making in Organisations in Sri Lanka: An Interpretative Phenomenological Analysis. *Journal of Business Ethics.*

Jiang, Y., Yin, S. and Kaynak, O., 2021. Performance Supervised Plant-Wide Process Monitoring in Industry 4.0: A Roadmap. *IEEE,* pp. 21-35.

JURKAT, W. B. and RYSER, H. J., 1966. Matrix Factorizations of Determinants and Permanents. *JOURNAL OF ALGEBRA 3,* pp. 1-27.

Kagioglou, M., Cooper, R., Aouad, G. and Sexton, M., 2000. Rethinking construction: the Generic Design and Construction Process Protocol. *Engineering, Construction and Architectural Management,* pp. 141-153.

Kamble, S., Gunasekaran, A. and Gawankar, S., 2018. Sustainable Industry 4.0 framework: a systematic literature review identifying the current trends and future perspectives. *Process Safety and Environmental Protection,* pp. 408-425.

Kamunda, A., Renukappa, S., Suresh, S. and Jallow, H., 2021. BIM in the water industry: addressing challenges to improve the project delivery process. *Engineering, construction, and architectural management,* pp. 510-529.

Kaplan, R. S., 2005. How the balanced scorecard complements the McKinsey 7-S model. *Strategy and leadership,* pp. 41-46.

Kauppi, K., 2013. Extending the use of institutional theory in operations and supply chain management research: Review and research suggestions. *International journal of operations and production management,* pp. 1318-1345.

Keeves, J., 1997. *Educational Research, Methodology and Measurement: An International Handbook Vol: 7.* Bingley: Emerald Group Publishing Limited.

KENTON, W., 2018. *Infrastructure.* [Online]
Available at: https://www.investopedia.com/terms/i/infrastructure.asp

Khan, I. S., Ahmad, M. O. and Majava, J., 2021. Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives. *Journal of Cleaner Production.*

Khan, I. S., Ahmad, M. O. and Majava, J., 2021. Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives. *Journal of Cleaner Production.*

Khan, S., 2021. *Covid just gave Industry 4.0 the push it needed in India [Company].* New Delhi: The Economic Times.

Khattak, M. S., Ur Rehman, A., Mustafa, U. and Khattak, I. U., 2016. Impact of Management Competencies and Complexities on Performance in Public Sector Infrastructure Projects of Pakistan. *NUML International Journal of Business and Management,* pp. 12-34.

KIEL, D., MÜLLER, J. M., ARNOLD, C. and VOIGT, K.-I., 2017. SUSTAINABLE INDUSTRIAL VALUE CREATION: BENEFITS AND CHALLENGES OF INDUSTRY 4.0. *International Journal of Innovation Management.*

Kimani, T. N., Jallow, H., Njuguna, M. B. and Alkizim, A., 2021. BIM Awareness: The Kenyan and UK Scenarios. *Collaboration and Integration in Construction, Engineering, Management and Technology ,* pp. 117-122.

Kitchenham, B. et al., 2009. Systematic literature reviews in software engineering – A systematic literature review. *Information and Software Technology,* pp. 7-15.

Knight, A. and Ruddock, L., 2008. *Advanced Research Methods in the Built Environment.* London: Wiley-Blackwell.

Koh, L., Orzes, G. and Jia. , F. (., 2019. The fourth industrial revolution (Industry 4.0): technologies disruption on operations and supply chain management. *International Journal of Operations and Production Management,* pp. 817-828.

Koh, L., Orzes, G. and Jia, F. (., 2019. The fourth industrial revolution (Industry 4.0): technologies disruption on operations and supply chain management. *International Journal of Operations and Production Management.*

Kor, Y. Y. and Mahoney, J. T., 2003. Edith Penrose's (1959) Contributions to the Resource-based View of Strategic Management. *Journal of Management Studies,* pp. 183-191.

Kotter, J. P. and Cohen., D. S., 2002. *The Heart of Change: Real-Life Stories of how People Change Their Organizations.* Boston, MA: Harvard Business Press.

Kovács, G. and Spens, K. M., 2005. Abductive reasoning in logistics research. *International Journal of Physical Distribution and Logistics Management,* pp. 132-144.

KPMG, 2015. *Infrastructure, building and construction.* [Online]
Available at: http://www.kpmg.com/uk/en/industry/buildingandconstruction/pages/default.aspx
[Accessed 09 November 2015].

Kumara, P., Sharma, D. and Pandey, P., 2022. Industry 4.0 (I4.0) Based Virtual Organization Model for the Coordination of Sustainable Textile Supply Chain. *American Business Review,* pp. 186-208.

Kumar, K., 1987. *CONDUCTING GROUP INTERVIEWS IN DEVELOPING COUNTRIES ,* Thailand: A.I.D. .

Kumar, P., 2021. An In-Depth Analysis of the Various Factors Influencing Industry 4.0 and its Impact on the Overall Performance of the Industrial Sector to Achieve Sustainable Development. *International Journal of Online and Biomedical Engineering,* pp. 34-46.

Kung, L., Cegielski, C. G. and Kung, H.-j., 2015. An integrated environmental perspective on software as a service adoption in manufacturing and retail firms. *Journal of Information Technology,* pp. 352363.

Kuznetsov, Y. and Dahlman, C. J., 2008. *Mexico's Transition to a Knowledge-Based Economy - Challenges and Opportunities.* Washington D.C. : The World Bank.

Kynge, J. and Lockett, H., 2020. *From cover-up to global donor: China's soft power play.* [Online] Available at: https://www.ft.com/content/efdec278-6d01-11ea-9bca-bf503995cd6f

Langar, S., 2017. Challenges with BIM Implementation: A Review of Literature. *ASC Annual International Conference Proceedings,* pp. 329-355.

Langhe, R. D. and Schliesser, E., 2017. Evaluating Philosophy as Exploratory Research. *Humanities International Complete.*

Lasi, H. et al., 2014. Industry 4.0. *Business and Information Systems Engineering,* pp. 239-242.

Latham, M., 1994. *CONSTRUCTING THE TEAM; Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry ,* London: Crown Copyright.

Levasseur, R. E., 2001. People Skills: Change Management Tools--Lewin's Change Model. *Interfaces (Providence),* pp. 71-73.

Liao, Z., 2017. Institutional pressure, knowledge acquisition and a firm's environmental innovation. *School of Economy and Management.*

Lieb, K. J. and Lieb, R. C., 2010. Environmental sustainability in the third-party logistics (3PL) industry. *International Journal of Physical Distribution and Logistics Management,* pp. 524-533.

Lindblad, H. and Guerrero, J. R., 2020. Client's role in promoting BIM implementation and innovation in construction. *Construction Management and Economics,* pp. 468-482.

Lin, T.-C. and Wang, K. J., 2021. Project-based maturity assessment model for smart transformation in Taiwanese enterprises. *PLoS ONE.*

Liu, L., 2016. Using Generic Inductive Approach in Qualitative Educational Research: A Case Study Analysis. *Journal of Education and Learning,* pp. 1-7.

Li, Y. and Liu, C., 2019. Applications of multirotor drone technologies in construction management. *International Journal of Construction Management,* pp. 401-412.

Longley, R., 2021. *Overview of the Second Industrial Revolution.* [Online]
Available at: https://www.thoughtco.com/second-industrial-revolution-overview-5180514 [Accessed 27 April 2023].

Longo, F., Nicoletti, L. and Padovano, A., 2017. Smart operators in industry 4.0: a human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. *Computers and Industrial Engineering,* pp. 144-159.

Loomis, C. P. and Pepinsky, H. B., 1948. Theory and Methods. *Sociometry,* pp. 262-286.

Löschel, A., Lutz, B. J. and Managi, S., 2019. The impacts of the EU ETS on efficiency and economic performance – An empirical analyses for German manufacturing firms. *Resource and energy economics,* pp. 71-95.

Lui, A. K., Ngai, E. W. and Lo, C. K., 2016. Disruptive information technology innovations and the cost of equity capital: The moderating effect of CEO incentives and institutional pressures. *Information and Management,* pp. 345-354.

Lui, Z. et al., 2021. Hard-rock tunnel lithology prediction with TBM construction big data using a global-attention-mechanism-based LSTM network. *Automation in Construction* .

Luthra, S. and Mangla, S. K., 2018. Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process Safety and Environmental Protection,* pp. 168-179.

Lu, Y., 2017. Industry 4.0: a survey on technologies, applications and open research issues. *Journal of Industrial Information Integration,* pp. 1-10.

Lu, Y., 2017. Industry 4.0: A survey on Technologies, Applications and open research Issues. *Journal of Industrial Information Integration,* pp. 1-10.

M.Müller, J., OanaBuliga and Kai-IngoVoigt, 2021. The role of absorptive capacity and innovation strategy in the design of industry 4.0 business Models - A comparison between SMEs and large enterprises. *European Management Journal,* pp. 333-343.

Machado, C. G. et al., 2019. Industry 4.0 readiness in manufacturing companies: Challenges and enablers towards increased digitalization. *Procedia CIRP.*

Machado, C. G., Winroth, M. P. and Silva, E. H. D. R. d., 2019. Sustainable manufacturing in Industry 4.0: an emerging research agenda. *International Journal of Production Research* , pp. 1462-1484.

Maeda, T. and Fujiwara, H., 2016. Seismic Hazard Visualization from Big Simulation Data: Construction of a Parallel Distributed Processing System for Ground Motion Simulation Data. *National Research Institute for Earth Science and Disaster Prevention (NIED),* pp. 265-271.

Magalhães, R. F. d., Danilevicz, Â. d. M. F. and Saurin, T. A., 2017. Reducing construction waste: A study of urban infrastructure projects. *Waste Management,* pp. 265-277.

Magrini, E., 2019. *Opportunity knocks? Economic outcomes for low-skilled people in cities.* [Online] Available at: https://www.centreforcities.org/reader/opportunity-knocks/the-economic-outcomes-oflow-skilled-people-in-urban-britain/

Malviya, R. K. and Kant, R., 2017. Modeling the enablers of green supply chain management. *Benchmarking,* pp. 536-568.

Manavalan, E. and Jayakrishna, K., 2019. A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. *Computers and Industrial Engineering,* pp. 925-953.

Mandele, M. V. D., 2006. Policy Development for Infrastructure Networks:Concepts and Ideas. *Journal of Infrastructure Systems.*

Mandhar, M. and Mandhar, M., 2013. BIMING THE ARCHITECTURAL CURRICULA – INTEGRATING BUILDING INFORMATION MODELLING (BIM) IN ARCHITECTURAL EDUCATION. *International Journal Of Architecture (IJA),* 1(1), pp. 1-20.

Markard, J., 2010. Infrastructure sector characteristics and implications for innovation and sectoral change. *Journal of Infrastructure Systems,* pp. 107-117.

Marques, M., Agostinho, C., Zacharewicz, G. and Jardim-Gonçalves, R., 2017. Decentralized decision support for intelligent manufacturing in Industry 4.0. *Journal of Ambient Intelligence and Smart Environments,* pp. 299-313.

Martínez-Ferrero, J. and García-Sánchez, I.-M., 2017. Coercive, normative and mimetic isomorphism as determinants of the voluntary assurance of sustainability reports. *International business review,* pp. 102-118.

Mason, M., 2010. *Sample Size and Saturation in PhD Studies Using Qualitative Interviews,* s.l.: Forum: Qualitative Social Research.

Mason, M., 2014. *Conject Blog.* [Online]
Available at: http://conjectblog.co.uk/2014/11/6-challenges-of-bim-adoption/ [Accessed 07 November 2015].

Masood, T. and Egger, J., 2019. Augmented reality in support of Industry 4.0—Implementation challenges and success factors. *Robotics and Computer Integrated Manufacturing,* pp. 181-195.

Masood, T. and Egger, J., 2019. Augmented reality in support of Industry 4.0—Implementation challenges and success factors. *Robotics and computer-integrated manufacturing,* pp. 181-195.

Masood, T. and Sonntag, P., 2020. Industry 4.0: adoption challenges and benefits for SMEs. *Computers in Industry,* 121(130261).

Maynard, K. and Ross, P., 2021. Towards a 4th industrial revolution. *Intelligent Buildings International , * Volume 13, pp. 159-161.

Mbambo, E., 2013. *Developing and integrating cultural competence into nursing education curricula: a qualitative grounded theory approach,* Wolverhampton: University of Wolverhampton.

MCCIP, 2020. *Marine Climate Change Impacts Report Card 2020,* World Land Trust: MCCIP.

McKinley, R. K., 2015. Qualitative and quantitative: the yin and the yang or the light and the dark sides of medical education?. *Springerlink.*

McKinsey and Company, 2022. *What are Industry 4.0, the Fourth Industrial Revolution, and 4IR?.* [Online]
Available at: https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-are-industry-40-the-fourth-industrial-revolution-and-4ir [Accessed 27 May 2023].

McKinsey Digital, 2017. *Industry 4.0 after the initial hype Where manufacturers are finding value and how they can best capture it,* Munich: McKinsey and Company .

Mcmahon, R. G. P., 2001. rowth and Performance of Manufacturing SMEs: The Influence of Financial Management Characteristics. *International Small Business Journal: Researching Entrepreneurship.*

Meeks, P., 2015. *Mckinsey and company.* [Online]
Available at: http://www.mckinsey.com/client_service/infrastructure/expertise/social_infrastructure [Accessed 06 December 2015].

Mehrabi, H., Coviello, N. and Ranaweera, C., 2021. When is top management team heterogeneity beneficial for product exploration? Understanding the role of institutional pressures. *Journal of Business Research,* pp. 775-786.

Meng, X. and Brown, A., 2018. Innovation in construction firms of different sizes: drivers and strategies. *Engineering, Construction and Architectural Management,* pp. 1210-1225.

Menon, S., Karl, J. and Wignaraja, K., 2009. *HANDBOOK ON PLANNING, MONITORING AND EVALUATING FOR DEVELOPMENT RESULTS.* New York: UNDP.

Merriam, S., 1998. *Qualitative Research and Case Study Applications in Education. Revised and Expanded from "Case Study Research in Education.".* San Francisco: Jossey-Bass Publishers.

Meyer, R. E. and Höllerer, M. A., 2014. Does Institutional Theory Need Redirecting?. *Journal of Management Studies,* pp. 221-1233.

Mhlanga, D., 2021. Artificial Intelligence in the Industry 4.0, and Its Impact on Poverty, Innovation, Infrastructure Development, and the Sustainable Development Goals: Lessons from Emerging Economies?. *Sustainability and Industry 4.0 in Civil and Infrastructure Engineering.*

Microsoft, 2019. *Accelerating competitive advantage with AI,* s.l.: Microsoft corporation.

Minc, H., 1978. *Permanents (Section, Linear algebra).* Reading: Addison-wesley.

Mingers, J., 2001. Combining IS Research Methods: Towards a Pluralist Methodology. *Information Systems Research.*

Mirzaei, K. et al., 2022. 3D point cloud data processing with machine learning for construction and infrastructure applications: A comprehensive review. *Advanced Engineering Informatics.*

Mishra, H. and Venkatesan, M., 2020. Blockchain in human resource management of organizations: an empirical assessment to gauge HR and non-HR perspective. *Journal of Organizational Change Management,* pp. 525 - 542.

Mitchell, A. J., 2018. A Review of Mixed Methods, Pragmatism and Abduction Techniques. *The Electronic Journal of Business Research Methods,* pp. 103-116.

Mohelska, H. and Sokolova, M., 2018. Management approaches for Industry 4.0 – the organizational culture perspective. *Technological and Economic Development of Economy,* pp. 2225 - 2240.

MOHELSKA, H. and SOKOLOVA, M., 2018. MANAGEMENT APPROACHES FOR INDUSTRY 4.0 – THE ORGANIZATIONAL CULTURE PERSPECTIVE. *Technological and Economic Development of Economy,* pp. 2225-2240.

Moher, D. et al., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.,* 6(7).

Moore, M., 2020. *What is Industry 4.0? Everything you need to know.* [Online]
Available at: https://www.techradar.com/news/what-is-industry-40-everything-you-need-to-know
[Accessed 28 April 2023].

Motawa, I., 2017. Spoken dialogue BIM systems – an application of big data in construction. *Emerald Publishing Limited,* pp. 787-800.

Mrugalska, B. and Wyrwicka, M., 2017. Towards lean production in industry 4.0. *Procedia Engineering,* pp. 218-235.

Mubarak, M. F. and Petraite, M., 2020. Industry 4.0 technologies, digital trust and technological orientation: What matters in open innovation?. *Technological Forecasting and Social Change.*

Muduli, K. and Barve, A., 2013. Sustainable development practices in mining sector: a GSCM approach. *Int. J. Environment and Sustainable Development.*

Muller, J., Kiel, D. and Voigt, K., 2018. What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability,* p. 247.

Müller, J. M., Buliga, O. and Voigt, K.-I., 2018. Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change,* pp. 2-17.

MÜLLER, J. M. and VOIGT, K., 2017. INDUSTRY 4.0 - INTEGRATION STRATEGIES FOR SMALL AND MEDIUM-SIZED ENTERPRISES. *International Association for Management of Technology* .

Muller, J. M. and Voigt, K.-I., 2018. The Impact of Industry 4.0 on Supply Chains in Engineer-to-Order Industries - An Exploratory Case Study. *IFAC,* pp. 122-127.

Murcia, N. N., Ferreira, F. A. and Ferreira, J. J., 2022. Enhancing strategic management using a "quantified VRIO": Adding value with the MCDA approach. *Technological forecasting and social change.*

Nafchi, M. Z. and Mohelská, H., 2020. Organizational Culture as an Indication of Readiness to Implement Industry 4.0. *www.mdpi.com/journal/information.*

Nascimento, D. L. M. et al., 2019. Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of Manufacturing Technology Management.*

NBS, 2017. *National BIM Report,* London: RIBA Enterprises Ltd.

NBS, 2020. *10th Annual BIM Report,* Newcastle upon Tyne: NBS Enterprises Ltd.

Nedelko, Z., 2021. What Drives the Usage of Management Tools Supporting Industry 4.0 in Organizations?. *Sensors.*

Nedelko, Z. and Potocan, V., 2021. The impact of COVID 19 on digitalization of organizations. *Management, Enterprise and Benchmarking in the 21st Century,* pp. 73-78.

Nena, T. D., Musonda, I. and Okoro, C. S., 2021. A Systematic Review of the Benefits of Automation Inspection Tools for Quality Housing Delivery. *Creative Construction Conference* .

Newman, I. and Benz, C. R., 1998. *Qualitative-Quantitative Research Methodology; Exploring the Interactive Continuum.* Board of Trustees, Southern Illinois University: Illinois.

Nickols, F., 2016. *Change Management 101,* s.l.: skullworks.

Nilsson, N. J., 1998. Artificial intelligence: a new synthesis. *Morgan Kaufmann Publishers Inc.*

Nissen, K. M. and Ulbrich, U., 2017. Increasing frequencies and changing characteristics of heavy precipitation events threatening infrastructure in Europe under climate change. *Nat. Hazards Earth Syst. Sci,* pp. 1177-1190.

Noardo, F. et al., 2019. GEOBIM BENCHMARK 2019: DESIGN AND INITIAL RESULTS. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*

Oghazi, P., Parida, V., Wincent, J. and Mostaghel, R., 2022. Ecosystems transformation through disruptive innovation: A definition, framework and outline for future research. *Journal of Business Research,* pp. 16-26.

Oracle, 2021. *Developing Applications with Oracle Internet of Things Cloud Service.* [Online] Available at: https://docs.oracle.com/en/cloud/paas/iot-cloud/iotgs/iot-digital-twin-framework.html

Oztemel, E. and Gursev, S., 2018. Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing,* pp. 1-56.

Panetto, H. et al., 2019. Challenges for the cyber-physical manufacturing enterprises of the future. *Annual Reviews in Control,* pp. 200-213.

Patel, P. C., Pearce, J. A. and Guedes, M. J., 2019. The Survival Benefits of Service Intensity for New Manufacturing Ventures: A Resource-Advantage Theory Perspective. *Journal of service research,* pp. 352-370.

Pearson, J., Pitfield, D. and Ryley, T., 2015. Intangible resources of competitive advantage: Analysis of 49 Asian airlines across three business models. *Journal of Air Transport Management,* pp. 179-189.

Piccarozzi, M., Aquilani, B. and Gatti, C., 2018. Industry 4.0 in management studies: a systematic literature review. *Sustainability,* p. 3821.

Pinsker, R. E. and Felden, C., 2016. Professional Role and Normative Pressure: The Case of Voluntary XBRL Adoption in Germany. *Journal of emerging technologies in accounting,* pp. 95-118.

Piroozfar, P. et al., 2019. Facilitating Building Information Modelling (BIM) using Integrated Project Delivery (IPD): A UK perspective. *Journal of Building Engineering.*

PlanRadar, 2022. *BIM adoption in the UK – history and impact.* [Online] Available at: https://www.planradar.com/gb/bim-in-uk-construction-technology-market/ [Accessed 27 April 2023].

Pollack, J. and Pollack., a. R., 2015. Using Kotter's Eight Stage Process to Manage an Organisational Change Program: Presentation and Practice. *Systemic Practice and Action Research 28,* pp. 51-66.

Pouspourika, K., 2019. *The 4 Industrial Revolutions.* [Online] Available at: https://ied.eu/project-updates/the-4-industrial-revolutions/

Pratt, D. D., 1987. Technology and instructional functions. *New Directions for Adult and Continuing Education.*

Primi, A. and Toselli, M., 2020. A global perspective on industry 4.0 and development: new gaps or opportunities to leapfrog?. *JOURNAL OF ECONOMIC POLICY REFORM,* pp. 371-389.

Prodi, E., Tassinari, M., Ferrannini, A. and Rubini, L., 2022. Industry 4.0 policy from a sociotechnical perspective: The case of German competence centres. *Technological Forecasting and Social Change.*

Qin', J., Liu, Y. and Grosvenor, R., 2016. A categorical framework of manufacturing for industry 4.0 and beyond. *Procedia CIRP,* pp. 173-178.

Qiu, T. and Yang, Y., 2018. Knowledge spillovers through quality control requirements on innovation development of global suppliers: The firm size effects. *Industrial Marketing Management,* pp. 171180.

R. Dubey, A. G. C. S. W. D. R. C. F., 2019. Empirical investigation of data analytics capability and organizational flexibility as complements to supply chain resilience. *International Journal of Production Research.*

RadhyaSahal, G.Breslin, J. and IntizarAli, M., 2020. Big data and stream processing platforms for Industry 4.0 requirements mapping for a predictive maintenance use case. *Journal of Manufacturing Systems,* pp. 138-151.

Rahman, S. M. et al., 2020. End-of-Life in industry 4.0: Ignored as before?. *Resources, Conservation and Recycling.*

Raicu, A. and Raicu, G., 2021. Digital Enterprise and Cyber Security Evolution. *Macromolecular Symposia.*

Rajesh, A., Nikhil, D. and Vivek, S., 2013. Graph Theoretic approach (GTA) – A Multi-Attribute Decision Making (MADM) Technique. *Research Journal of Engineering Sciences,* pp. 50-53.

Rajesh, R., 2017. Technological capabilities and supply chain resilience of firms: A relational analysis using Total Interpretive Structural Modeling (TISM). *Technological Forecasting and Social Change,* pp. 161-169.

Ram, J., Afridi, N. and Khan, K. A., 2019. Adoption of Big Data analytics in construction: development of a conceptual model. *Built Environment Project and Asset Management,* 9(4).

Rao, R. V., 2007. A material selection model using graph theory. *Materials Science and Engineering A ,* pp. 248-255.

Rasheed, A., San, O. and Kvamsdal, T., 2020. Digital Twin: Values, Challenges and Enablers From a Modeling Perspective. *ieee,* pp. 21980-22012.

Rasheed, A., San, O. and Kvamsdal, T., 2020. Digital Twin: Values, Challenges and Enablers From a Modeling Perspective. *IEEE,* pp. 21980-22012.

Ratnasingam, J. et al., 2019. Extent of automation and the readiness for industry 4.0 among Malaysian furniture manufacturers. *BioRes.,* pp. 7095-7110.

Rauch, E., Vickery, A. R., Brown, C. A. and Matt, D. T., 2020. SME Requirements and Guidelines for the Design of Smart and Highly Adaptable Manufacturing Systems. *Faculty of Science and Technology.*

Reim, W., Parida, V. and Ortqvist, D., 2015. ProducteService Systems (PSS) business models and tactics e a systematic literature review. *Journal of Cleaner Production,* pp. 61-75.

Reyes-Veras, P. F., Renukappa, S. and Suresh, S., 2021. CHALLENGES FACED BY THE ADOPTION OF BIG DATA IN THE DOMINICAN REPUBLIC CONSTRUCTION INDUSTRY: AN EMPIRICAL STUDY. *Journal of Information Technology in Construction.*

Reyes-Veras, P. F., Renukappa, S. and Suresh, S., 2021. CHALLENGES FACED BY THE ADOPTION OF BIG DATA IN THE DOMINICAN REPUBLIC CONSTRUCTION INDUSTRY: AN EMPIRICAL STUDY. *Journal of Information Technology in Construction.*

Reyes-Veras, P. F., Renukappa, S., Suresh, S. and Algahtani, K., 2022. STRATEGIES FOR IMPLEMENTING BIG DATA CONCEPT IN THE CONSTRUCTION INDUSTRY OF THE DOMINICAN REPUBLIC. *21st International Conference on Construction Applications of Virtual Reality,* pp. 210-219.

Reynolds, M. and Weiss, S., 2020. *How coronavirus started and what happens next, explained.* [Online]
Available at: https://www.wired.co.uk/article/china-coronavirus

RICS, 2017. *Building Information Modelling for Project Managers,* London: Royal Institution of Chartered Surveyors (RICS).

Ritchie, J., Lewis, J. and Nicholls, C. M., 2014. *Qualitative research Practive.* Singapore: SAGE Pupblications Ltd.

Roberts, B. H., 2015. The Third Industrial Revolution: Implications for Planning Cities and Regions. *Working Paper Urban Frontiers.*

Robinson, H. S., Anumba, C. J., Carrillo, P. M. and Al-Ghassani, A. M., 2006. STEPS: a knowledge management maturity roadmap for corporate sustainability. *Business Process Management Journal,* p. 763.

Rojko, A., 2017. Industry 4.0 Concept: Background and Overview. *International Journal of Interactive Mobile Technologies.*

Ruben, R. B. and Varthanan, P. A., 2019. Application of Total Interpretive Structural Modeling (TISM) Approach for Analysis of Barriers in Deploying Circular Supply Chains. *Indian Journal of Science and Technology.*

Saberi, S. and Yusuff, R. M., 2010. Neural network application in predicting advanced manufacturing technology implementation performance. *Neural Computing and Applications.*

Salehi, S., Arashpour, M., Kodikara, J. and Guppy, R., 2021. Sustainable pavement construction: A systematic literature review of environmental and economic analysis of recycled materials. *Journal of Cleaner Production .*

Sánchez-López, R., Echeazarra, I. and Castellano, J., 2022. Systematic review of declarative tactical knowledge evaluation tools based on game-play scenarios in soccer. *Quality and Quantity,* pp. 2157 - 2176.

Sanders, A., Elangeswaran, C. and Wulfsberg, J., 2016. Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing. *Journal of Industrial Engineering and Management.*

Santos, G. et al., 2021. New Needed Quality Management Skills for Quality Managers 4.0. *Sustainability.*

Saraji, M. K., Streimikiene, D. and Kyriakopoulos, G. L., 2021. Fermatean Fuzzy CRITIC-COPRAS Method for Evaluating the Challenges to Industry 4.0 Adoption for a Sustainable Digital Transformation. *Sustainability.*

Saraji, M. K., Streimikiene, D. and Kyriakopoulos, G. L., 2021. Fermatean Fuzzy CRITIC-COPRAS Method for Evaluating the Challenges to Industry 4.0 Adoption for a Sustainable Digital Transformation. *Digitalization and Sustainable Development.*

Sari, T. K., Cahaya, F. R. and Joseph, C., 2020. Coercive Pressures and Anti-corruption Reporting: The Case of ASEAN Countries. *Springer Nature B.V. .*

Sariwulan, T. and Suparno, S., 2020. Factors Explaining the Performance of Entrepreneurs in the Industry 4.0: A Theoretical Approach. *Jurnal Pendidikan Ekonomi and Bisnis,* pp. 154-164.

Sarrakh, R., Renukappa, S. and Suresh, S., 2021. A systematic literature review evaluating sustainable energy growth in Qatar using the PICO model. *AAM.*

Sarros, J. C., Cooper, B. K. and Santora, J. C., 2011. Leadership vision, organizational culture, and support for innovation in not-for-profit and for-profit organizations. *Leadership and Organization Development Journal,* pp. 291-309.

Satyro, W. C. et al., 2022. Industry 4.0 implementation: The relevance of sustainability and the potential social impact in a developing country. *Journal of Cleaner Production.*

Saunders, M., 2009. *Research Methods for business students.* Harlow: Pitman Publishing.

Savas, B. M., Emin, O., Emel, L. O. and Atis, C. D., 2015. Comparison of multi layer perceptron (MLP) and radial basis function (RBF) for construction cost estimation: the case of Turkey. *Journal of Civil Engineering and Management,* pp. 480-490.

Scherpenisse, J., 2012. Improving Construction Productivity: Time and Motion. *Best Practices Conference,* pp. 2-20.

Schneider, P. and Sting, F. J., 2020. Employees' Perspectives on Digitalization-Induced Change: Exploring Frames of Industry 4.0. *Academy of Management discoveries,* pp. 406-435.

Schwandt, T., 2000. Three epistemological stances for qualitative inquiry: Interpretivism, hermeneutics, and social constructivism. *Handbook of Qualitative Research,* pp. 189-214.

Scotland, J., 2012. Exploring the Philosophical Underpinnings of Research: Relating Ontology and Epistemology to the Methodology and Methods of the Scientific, Interpretive, and Critical Research Paradigms. *Canadian Center of Science and Education ,* pp. 9-16.

Seneviratne, W., 2015. Modeling survey research designs: a review of basic design phases for effective reasoning for novice LIS researchers. *International Conference of National Institute of Library and Information Science.*

Shaheer, M., Bavle, H., Sanchez-Lopez, J. L. and Voos, H., 2023. Robot Localization Using Situational Graphs (S-Graphs) and Building Architectural Plans. *Robotics ,* 3(65), p. 12.

Shamim, S., Cang, S., Yu, H. and Li, Y., 2016. Management approaches for Industry 4.0: A human resource management perspective. *IEEE Congress on Evolutionary Computation (CEC),* pp. 53095316.

Sharif, M.-M., Nahangi, M., Haas, C. and West, J., 2017. Automated Model-Based Finding of 3D Objects in Cluttered Construction Point Cloud Models. *Computer-Aided Civil and Infrastructure Engineering,* pp. 893-908.

Sherri, 2012. *THE SIX STAGE OF CHANGE OR THE 6 C'S.* [Online]
Available at: https://technacon.com/philip-crosby-quality-management-philosophy/the-six-stage-ofchange-or-the-6-cs.htm [Accessed 07 May 2023].

Shet, S. V. and Pereira, V., 2021. Proposed managerial competencies for Industry 4.0 – Implications for social sustainability. *Technological Forecasting and Social Change.*

Shulga, L. V., 2020. Change Management Communication: The Role of Meaningfulness, Leadership Brand Authenticity, and Gender. *Cornell Hospitality Quarterly.*

Silva, D. J., Santos, R. and Santos, I., 2020. Industry Innovations 4.0 Process Management in the Provision of Services in the Construction Industry. *Future Studies Research Journal: Trends and Strategies,* pp. 394-415.

Simic, M. and Nedelko, Z., 2019. DEVELOPMENT OF COMPETENCE MODEL FOR INDUSTRY 4.0: A THEORETICAL APPROACH. *Economic and Social Development: Book of Proceedings,* pp. 1288-1298.

Singh, M. K., Kumar, H., Gupta, M. and Madaan, J., 2018. Competitiveness of Electronics manufacturing industry in India: an ISM–fuzzy MICMAC and AHP approach. *MEASURING BUSINESS EXCELLENCE* .

Singh, R., 2018. *The bond between Artificial Intelligence and Knowledge Management.* [Online] Available at: https://curatti.com/artificial-intelligence-knowledge-management/

Slåtten, T., Mutonyi, B. R. and Lien, G., 2021. Does organizational vision really matter? An empirical examination of factors related to organizational vision integration among hospital employees. *BMC Health Services Research.*

Slávik, Š. and Bednár, R., 2014. Analysis of Business Models. *Journal of competitiveness,* pp. 19-40.

Smith, D. K., 2009. *Building Information Modeling.* New Jersey: John Wiley and Sons.

Smith, J. A., 2012. *Fig.net.* [Online]
Available at: https://www.fig.net/resources/monthly_articles/2012/june_2012/june_2012_smith.pdf
[Accessed 04 November 2015].

Song, B. and Zhao, Z., 2021. Institutional pressures and cluster firms' ambidextrous innovation: the mediating role of strategic cognition. *Chinese Management Studies,* pp. 245-262.

Stachowicz, J., Stachowicz-Stanusch, A. and Ledzianowski, J., 2021. Problems of Organizing Changes in the Management of Enterprises Implementing Technologies According to Concept "Industry 4.0". *European Research Studies Journa,* pp. 288-303.

Stake Market Report, 2014. *The business value of BIM for Construction in major global markets,* Bedford: McGraw Hill Construction.

Stanford , 2020. *Epistemology.* [Online]
Available at: https://plato.stanford.edu/entries/epistemology/

Stock, T. and Seliger, G., 2016. Opportunities of Sustainable Manufacturing in Industry 4.0. *13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use.*

Succar, B., 2012. Macro BIM adoption: conceptual structures. *Teesside University,* pp. 1-35.

Suresh, S. et al., 2020. Developments in the UK road transport from a smart cities perspective. *Engineering Construction and Architectural Management.*

Surg, I. J., 2020. The Socio-Economic Implications of the Coronavirus and COVID-19 Pandemic: A Review. *International Journal of Surgery (London, England).*

Sushil, S., 2012. Interpreting the interpretive structural model. *Global Journal of Flexible Systems Management 13,* pp. 87-106.

Tahmasebinia, F. et al., 2020. Criteria development for sustainable construction manufacturing in Construction Industry 4.0: Theoretical and laboratory investigations. *Construction Innovation,* pp. 370-400.

Talaja, A., 2012. TESTING VRIN FRAMEWORK: RESOURCE VALUE AND RARENESS AS SOURCES OF COMPETITIVE ADVANTAGE AND ABOVE AVERAGE PERFORMANCE. *Management : Journal of Contemporary Management Issues,* pp. 51-64.

Talib, F. and Rahman, Z., 2019. Modeling the barriers toward the growth of higher education institutions: A total interpretive structural modeling approach. *Qualitative Journal Research,* pp. 243264.

Tang, M. et al., 2018. Atmosphere-vegetation-soil interactions in a climate change context; Impact of changing conditions on engineered transport infrastructure slopes in Europe. *Quarterly Journal of Engineering Geology and Hydrogeology.*

Tang, P. et al., 2010. Automatic reconstruction of as-built building information models from laserscanned point clouds: A review of related techniques. *Automation in Construction,* pp. 829-843.

Tashakkori, A. and Creswell, J. W., 2007. Exploring the Nature of Research Questions in Mixed Method Research. *Journal of Mixed Methods,* pp. 207-211.

Tate, W. L. and Bals, L., 2018. Achieving Shared Triple Bottom Line (TBL) Value Creation: Toward a Social Resource-Based View (SRBV) of the Firm. *J Bus Ethics.*

Taylor, S., 2017. What Is Innovation? A Study of the Definitions, Academic Models and Applicability of Innovation to an Example of Social Housing in England. *Journal of Social Sciences,* pp. 128-146.

Teddlie, C. and Tashakkori, A., 2012. Common “Core” Characteristics of Mixed Methods Research: A Review of Critical Issues and Call for Greater Convergence. *American Behavioral Scientist ,* pp. 774788.

The Economist, 2012. *The third industrial revolution.* [Online]
Available at: https://www.economist.com/leaders/2012/04/21/the-third-industrial-revolution

The Inestopedia team, 2022. *Infrastructure.* [Online]
Available at: https://www.investopedia.com/terms/i/infrastructure.asp

The KPI Team, 2016. *UK Industry Performance Report,* London: The KPI Team.

Thomas, D. R., 2006. A General Inductive Approach for Analyzing Qualitative Evaluation Data. *American Journl of Evaluation.*

Tinkler, L., Smith, V., Yiannakou, Y. and Robinson, L., 2017. Professional identity and the Clinical Research Nurse: A qualitative study exploring issues having an impact on participant recruitment in research. *Journal of Advanced Nursing,* pp. 318-328.

Too, E., 2011. Capability for Infrastructure Asset Capacity Management. *International Journal of Strategic Property Management,* pp. 139-151.

Too, E., Betts, M. and Arun, K., 2006. A strategic approach to Infrastructure Asset Management.

Torok, L., 2020. Industry 4.0 from a few aspects, in particular in respect of the decision making of the management /Will the new industrial revolution change the traditional management functions?/. *International Review of Applied Sciences and Engineering,* pp. 140-146.

Tortorella, G. L., Vergara, A. M. C., Garza-Reyes, J. A. and Sawhney, R., 2020. Organizational learning paths based upon industry 4.0 adoption: An empirical study with Brazilian manufacturers. *International Journal of Production Economics,* pp. 284-294.

Trimbath, S., 2011. *Chamber of comerce of the United States of America.* [Online] Available at:
https://www.uschamber.com/sites/default/files/legacy/issues/infrastructure/files/LRA_Index_Economic_Analysis_2011_10_17.pdf
[Accessed 06 December 2015].

Trochim, W. and Donnelly, J., 2006. *The Research Methods Knowledge Base.* Cincinnati: Atomic Dog.

Trochim, W. M., 2006. *Deduction and Induction.* [Online]
Available at: https://socialresearchmethods.net/kb/dedind.php

Trstenjak, M., Opetuk, T., Cajner, H. and Hegedić, M., 2022. Industry 4.0 Readiness Calculation—Transitional Strategy Definition by Decision Support Systems. *MDPI.*

Tvaronaviciene, M. and Burinskas, A., 2020. INDUSTRY 4.0 SIGNIFICANCE TO COMPETITION AND THE EU COMPETITION POLICY: A LITERATURE REVIEW. *Economics and Sociology,* pp. 244-258.

UK Commission for Eployment and Skills, 2016. *EmployerSkills Survey 2015:UK Results,* London: UKCES.

Umar, A., Sasongko, A. H., Aguzman, G. and Sugiharto, 2018. BUSINESS MODEL CANVAS AS A SOLUTION FOR COMPETING STRATEGY OF SMALL BUSINESS IN INDONESIA.

International journal of entrepreneurship, pp. 1-9.

Usubiaga-Liaño, A. and Ekins, P., 2021. Monitoring the environmental sustainability of countries through the strong environmental sustainability index. *Ecological Indicators.*

Usubiaga-Liaño, A. and Ekins, P., 2021. Monitoring the environmental sustainability of countries through the strong environmental sustainability index. *Ecological Indicators.*

Vaidya, S., Ambad, P. and Bhosle, S., 2018. Industry 4.0 – A Glimpse. *Procedia Manufacturing,* Volume 20, pp. 233-238.

Vaismoradi, M., Turunen, H. and Bondas, T., 2013. Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing and Health Sciences,* pp. 398-405.

Vale, R., 2016. *Second Industrial Revolution: The Technological Revolution.* [Online] Available at: https://richmondvale.org/en/blog/second-industrial-revolution-the-technologicalrevolution

Viale, L. and Zouari, D., 2020. Impact of digitalization on procurement: the case of robotic process automation. *Supply Chain Forum: An International Journal,* 21(3), pp. 185-195.

Villalba-Diez, J. and Ordieres-Mere, J., 2021. Human–Machine Integration in Processes within Industry 4.0 Management. *JIDOKA. Integration of Human and AI within Industry 4.0 Cyber Physical Manufacturing Systems.*

Vlachopoulou, M., Ziakis, C., Vergidis, K. and Madas, M., 2021. Analyzing AgriFood-Tech e-Business Models. *Information Systems and e-Business (ISEB) Lab, Department of Applied Informatics.*

Vuksanović Herceg, I., Kuč, V., Mijušković, V. M. and Herceg, T., 2020. Challenges and Driving Forces for Industry 4.0 Implementation. *Sustainability,* p. 4208.

Vyas, K., 2018. *How the First and Second Industrial Revolutions Changed Our World.* [Online] Available at: https://interestingengineering.com/how-the-first-and-second-industrial-revolutionschanged-our-world

W.Wirtz, B., Schilke, O. and Ullrich, S., 2010. Strategic Development of Business Models: Implications of the Web 2.0 for Creating Value on the Internet. *Long Range Planning,* pp. 272-290.

Waghorn, T., 2011. *Jeremy Rifkin's Third Industrial Revolution.* [Online] Available at: https://www.forbes.com/sites/terrywaghorn/2011/12/12/jeremy-rifkins-third-industrialrevolution/#7ab809b046f1

Waschneck, B., Altenmuller, T., Bauernhansl, T. and Kyek, A., 2016. Production Scheduling in Complex Job Shops from an Industry 4.0 Perspective: A review and challenges in the semiconductor Industry. *SAMI@iKNOW.*

Watterson, A., 2020. COVID-19 in the UK and Occupational Health and Safety: Predictable not Inevitable Failures by Government, and Trade Union and Nongovernmental Organization Responses. *SAGE.*

Weber, B., 2010. *Infrastructure as an asset class.* first ed. West Sussex: John Wiley and sons.

Webster, M., 2019. *Infrastructure.* [Online]
Available at: https://www.merriam-webster.com/dictionary/infrastructure

Wentworth, D. K., Behson, S. J. and Kelley, C. L., 2018. Implementing a new student evaluation of teaching system using the Kotter change model. *Studies in Higher Education,* pp. 511-523.

Weyer, S., Schmitt, M., Ohmer, M. and Gorecky, D., 2015. Towards Industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems. *IFAC,* pp. 579-584.

Weyer, S., Schmitt, M., Ohmer, M. and Gorecky, D., 2015. Towards Industry 4.0-standardization as the crucial challenge for highly modular, multi-vendor production systems. *Ifac-Papersonline,* pp. 579584.

Wolf, M. et al., 2018. CURRENT AND FUTURE INDUSTRIAL CHALLENGES: DEMOGRAPHIC CHANGE AND MEASURES FOR ELDERLY WORKERS IN INDUSTRY 4.0. *Annals of Faculty Engineering Hunedoara,* pp. 67-76.

Wollschlaeger, M., Zelm, M., Doumeingts, G. and Jaekel, F.-W., 2018. *Enterprise Interoperability: Smart Services and Business Impact of Enterprise Interoperability.* s.l.:Wiley-ISTE.

World Economic Forum, 2019. *Transforming Infrastructure: Frameworks for Bringing the Fourth Industrial Revolution to Infrastructure,* Switzerland: World Economic Forum.

World Economic Forum, 2020. *Fourth Industrial Revolution.* [Online]
Available at: https://www.weforum.org/focus/fourth-industrial-revolution

World Health Organisation, 2020. *Coronavirus.* [Online]
Available at: https://www.who.int/health-topics/coronavirus#tab=tab_1

Worldometer, 2020. *COVID-19 CORONAVIRUS PANDEMIC.* [Online] Available at: https://www.worldometers.info/coronavirus/

Wu, Y.-J., Hayat, T. and Clarens, A., 2013. Climate Change Effects on Transportation Infrastructure: Scenario-Based Risk Analysis Using Geographic Information Systems. *Energy and Global Climate Change,* pp. 71-81.

Yan, H., 2020. *The Spanish flu killed more than 50 million people. These lessons could help avoid a repeat with coronavirus.* [Online]

Available at: https://edition.cnn.com/2020/04/16/health/spanish-flu-coronavirus-lessonslearned/index.html

Yilmaz, A., Dora, M., Hezarkhani, B. and Kumar, M., 2022. Lean and industry 4.0: Mapping determinants and barriers from a social, environmental, and operational perspective. *Technological Forecasting and Social Change.*

Yin, R. K., 2015. *Qualitative Research from Start to Finish, Second Edition.* New York: Guilford Publications.

Yi, W. and Sutrisna, M., 2021. Drone scheduling for construction site surveillance. *WILEY,* pp. 3-13.

Yli-Ojanperä, M., Sierla, S., Papakonstantinou, N. and Vyatkin, V., 2019. Adapting an agile manufacturing concept to the reference architecture model industry 4.0: A survey and case study. *Journal of Industrial Information Integration,* pp. 147-160.

Yoo, Y., Richard J. Boland, J., Lyytinen, K. and Majchrzak, A., 2012. Organizing for Innovation in the Digitized World. *Organization Science.*

Yu, Y., Zhang, J. Z., Cao, Y. and Kazancoglu, Y., 2021. Intelligent transformation of the manufacturing industry for Industry 4.0: Seizing financial benefits from supply chain relationship capital through enterprise green management. *Technological Forecasting and Social Change.*

Yu, Z., Khan, S. A. R. and Umar, M., 2022. Circular economy practices and industry 4.0 technologies: A strategic move of automobile industry. *Business strategy and the environment,* pp. 796-809.

Zalaghi, H. and Khazaei, M., 2016. The Role of Deductive and Inductive Reasoning in Accounting Research and Standard Setting. *Asian Journal of Finance and Accounting.*

Zaman, R., 2020. *Unfolding Fourth Industrial Revolution—waves of creative destructions.* [Online] Available at: https://www.the-waves.org/2020/07/15/fourth-industrial-revolution/ [Accessed 27 April 2023].

ZANDER, U. and KOGUT, B., 1995. KNOWLEDGE AND THE SPEED OF THE TRANSFER AND IMITATION OF ORGANIZATIONAL CAPABILITIES - AN EMPIRICAL-TEST. *Organisation Science,* pp. 76-92.

Zaychenko, I., Smirnova, A. and Borremans, A., 2018. Digital transformation: the case of the application of drones in construction. *MATEC.*

Zhu, Q. and Geng, Y., 2013. Drivers and barriers of extended supply chain practices for energy saving and emission reduction among Chinese manufacturers. *Journal of Clean Production,* pp. 8-12.

Zidane, Y. J.-T., Hussein, B. A., Johansen, A. and Andersen, B., 2016. PESTOL - Framework for «Project Evaluation on Strategic, Tactical and Operational Levels». *International Journal of Information systems and project management.*

Žižek, S. Š., Nedelko, Z., Mulej, M. and Čič, Ž. V., 2020. Key Performance Indicators and Industry 4.0 – A Socially Responsible Perspective. *Naše gospodarstvo/Our Economy,,* pp. 22-35.

Zoubek, M. and Simon, M., 2021. Evaluation of the Level and Readiness of Internal Logistics for Industry 4.0 in Industrial Companies. *Advanced Design and Manufacturing in Industry 4.0.*

APPENDIX A – REVIEW PROTOCOL FOR SYSTEMATIC LITERATURE REVIEW

1. Background

a. Research gap

- The UK infrastructure sector has had a great interest since the early 2010s from both the industry and academically. Since, there have been multiple researchers who have studied digitisation, automation, and sustainable practices in the sector.
- The measure of value that organisations gain from already implementing strategies in the infrastructure sector.

b. Research question

What are the main industry 4.0 strategies that have been implemented in the UK infrastructure sector?

c. Bonus research questions

None.

2. Search plan

a. Search Approach

An automated search was conducted to find literature to support the study. The use of computer databases and online libraries allowed a faster way of finding relevant literature. Additionally, the availability of filtering enables easier cutting down of the results to find the information required.

b. Keywords and terms used for search.

UK Industry 4.0 development; Infrastructure sector; technology-based policies; Industry 4.0 development; Industry 4.0 goals; UK's economic development; UK's environmental development; UK'S social development; Industry 4.0 performance; Infrastructure sector performance; Infrastructure sector digitisation; Infrastructure sector Automation; Knowledge management; industry 4.0 development practices; industry 4.0 management; and UK's digital vision.

c. Database platforms

Directory of Open Access Journals, Scopus, ProQuest, SpringerLink, Elsevier and Scholar. ***d.***

Search Plan

Target dates were set before the start of conducting a review of the literature to have targeted timeframes for completing the task in time. The target dates were set with input from members of the panel and contributing authors.

Period (weeks)	**Stage**
4	Formulation of the review protocol
12	Exploration of the relevant studies
6	Assessment of Inclusion in the Studies
10	Data collection
7	Analysis of data
6	Documenting and dissemination

e. Search process supplementary

Researchers focusing on industry 4.0, policy and firms with experts within the infrastructure sector.

3. Selection Conditions

a. Criteria included.

	Inclusion conditions
Date	2010 – 2022
Location	UK
Language	English
Type	Research papers, articles, and books
Publications	Organisation and government reports, published books, peer-reviewed journals, and articles.
Participants	Organisations in the UK infrastructure sector
Design	Case study, qualitative, and theoretical studies

Focus	Does the study examine UK's infrastructure sector and industry 4.0 strategies? Does the study include industry 4.0 strategies within the UK
	infrastructure sector?

b. Criteria excluded.

	Exclusion conditions
Date	Before 2010
Location	
Language	Papers in other languages
Type	Book reviews, notes, and research thesis
Publications	Papers focussed on industrial topics
Participants	
Design	Papers with no structure or data or research process
Focus	Studies with no link to Industry 4.0 strategies

c. Disagreement resolution

Each article was reviewed and assessed by the reviewers which were focused on the topics that are related to the UK infrastructure sector or industry 4.0 development. The disagreements were put up for discussion during panels to find resolutions.

4. Extraction of data

a. Data extraction form

The data extraction form can be seen in Appendix B.

b. Data extraction strategy

Microsoft Excel was used and made available on OneDrive for the data extraction process. The reviewers added extracted data onto the spreadsheet to allow easier analysis. This method of data extraction was chosen as it provided an easy solution for the reviewers to access the data and additionally provided a summary which can be easily assessed.

5. Synthesis

a. Analysis method

For the synthesis of this study, the interpretive and inductive approach was chosen as it allowed the researcher to gather insight into the studies selected.

6. Selection of research

a. Result of journal articles summary

Data Platform	*Number of papers*
Elsevier	14
SpringerLink	8
ProQuest	7
Scholar	4
Scopus	9
Directory of Open Access Journals	11

APPENDIX B – DATA EXTRACTION FORM

Reviewer name:	Date:
Author/Authors:	Years:
Journal name:	Record:

Methodology of research:

Contributors:

Developing themes:

Synthesis:

APPENDIX C – EMAILS SENT TO PARTICIPANTS FOR INTERVIEW INVITATION

Research Invitation - Industry 4.0 Strategies in the UK Transport Infrastructure Sector

Dear Sir/Madamme

My name is Haddy Jallow and I am a research student at the University of Wolverhampton. I am conducting research with the general aim of investigating the challenges within the UK infrastructure and how to compete with other nations to boost the infrastructure sector's productivity, sustainability, and work practices. The research will explore strategies and Industry 4.0 technologies being implemented in the infrastructure sector from Artificial Intelligence to Virtual Reality. Alternative solutions to outdated current practices will be explored to improve productivity within the infrastructure sector while improving health and safety and general issues. I would like to invite you to be a participant in the above research project, as you are possibly influential for the adoption of Industry 4.0 strategies in the UK Infrastructure Sector.

In the document attached, you can find an invitation letter to the research explained above which defines the terms of confidentiality. Also, a consent form needs to be signed by the participant.

If you decide to participate in the research activity, could you please inform us when we could hold the interview?

Kind Regards,

Haddy Jallow

APPENDIX D – SEMI-STRUCTURED INTERVIEWS PROTOCOL

UNIVERSITY OF WOLVERHAMPTON
KNOWLEDGE ▪ INNOVATION ▪ ENTERPRISE

Information Sheet

SUSTAINED COMPETITIVE ADVANTAGE USING INDUSTRY 4.0 STRATEGIES: A CASE OF THE INFRASTRUCTURE SECTOR.

Dear Potential Participant,

My name is Haddy Jallow, and I am a research student at the University of Wolverhampton. The general aim of this research is to investigate the challenges within the UK infrastructure and how to compete with other nations to boost the infrastructure sector's productivity, sustainability, and work practices. The research will explore strategies and Industry 4.0 technologies being implemented in the infrastructure sector from Artificial Intelligence to Virtual Reality. Alternative solutions to outdated current practices will be explored to improve productivity within the infrastructure sector while improving health and safety and general issues. I would like to invite you to be a participant in the above research project, as you are possibly influential for the adoption of Industry 4.0 strategies in the UK Infrastructure Sector.

If you agree to participate you will be asked to:

- Participate in an interview (lasting a maximum of 30 minute's duration) with me answering questions regarding Industry 4.0 strategies within the UK Infrastructure sector to improve the UK infrastructure sector competitiveness. Questions will be topic on the topic above and not of a personal nature. You will not be asked to reveal any information which your organization would regard as sensitive and not for public disclosure. You can choose not to answer questions.
- Complete the attached consent form and return it to me.

With your consent, the interviews will be recorded and then transcribed on a computer system. You may review, edit, or erase the transcripts and recordings of your interview if this is your choice. Recordings will then be destroyed. Your responses will be treated as confidential and computer transcripts will not contain references to any persons (including yourself) or organizations. Such references will be replaced with codes known only to me, and all data will be kept securely.

Upon completion, a summary of the results will be made available after this research study. If you wish to attain a copy of these results, please provide your contact details. Please note that all the data gathered for this research will be kept securely and destroyed once the report has been submitted. The supervision team and I will be the only people with access to this data.

Thank you for taking the time to consider this invitation and if you choose to participate in this research. I would like to extend my gratitude; your contribution is greatly appreciated.

University of Wolverhampton
Wulfruna Street, City Campus
WV1 1LY

SEMI-STRUCTURED INTERVIEW QUESTIONS

Date	
Time of interview	
Organisation	
Line of business	

<table>
<tr><td></td><td>Name of Interviewee</td><td></td></tr>
<tr><td></td><td>Position of Interviewee</td><td></td></tr>
<tr><td></td><td>Organisation total employee size</td><td></td></tr>
<tr><td></td><td>Is your organisation Local to UK or International?</td><td></td></tr>
<tr><td></td><td colspan="2">Please kindly tell me a little about what your current job role is in the organisation.</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2">• What do you think is the status of the infrastructure sector concerning digitalisation?
• How long have you been involved in the digitalisation in your sector?
• Given your role in this organisation, please explain what does “industry 4.0” mean to you and your organisation?</td></tr>
<tr><td></td><td colspan="2">• Can you describe the key drivers that have fuelled the need for embracing Industry 4.0 agenda in your organisation?
(e.g. Government push, Competitiveness, Innovation, Reputation building, Clients demand, Cost savings, Top management commitment)</td></tr>
<tr><td colspan="3">The next few questions will focus on the adoption of Industry 4.0 strategies that have been implemented in your organisation.</td></tr>
<tr><td></td><td colspan="2">• From the job role and responsibilities that you perform in this organisation, please, describe the key ‘Industry 4.0 strategies that are currently being adopted in your organisation
(e.g. Predesign stage, During the design stage, Construction stage, Asset Maintenance and Management stage, Throughout the project’s lifecycle)

• In your view, kindly explain the key Industry 4.0 technologies that have been adopted within your organisation.
(e.g. AI, Drones, BIM, AR, VR, Big data, Point cloud, Block Chain)</td></tr>
</table>

	• Please enlighten me on the key change management strategies being implemented in your organisation to manage Industry 4.0 agenda. (e.g. Vision/mission; structural change; training and education; reward systems; KPIs; knowledge management)
The discussions have been very interesting. The next few questions will focus on the main challenges organisations face in implementing Industry 4.0 agenda.	
	• From the job role and responsibilities that you perform in this organisation, please,
	enlighten me on the main challenges your organisation face in implementing Industry 4.0 agenda.
The next few questions will focus on the impact of Industry 4.0 agenda on organisational competitiveness.	
	• Given your job roles and responsibility, kindly explain how the efforts of Industry 4.0 agenda have contributed to your organisation's competitiveness. (e.g. Improved client satisfaction, improved cost savings, enhanced organisation reputation, etc.) • In your view is there a need for developing an innovative business model for adopting Industry 4.0 agenda?

Consent form

SUSTAINED COMPETITIVE ADVANTAGE USING INDUSTRY 4.0 STRATEGIES: A CASE OF THE INFRASTRUCTURE SECTOR

Consent Statement

- I agree to participate in the above research project and give my consent freely.
- I understand that the project will be conducted as described in the "Information Sheet", a copy of which I have retained.
- I understand that I can withdraw from the project at any time and do not have to give a reason for withdrawing.
- I consent to participate in an interview with the researcher.
- I understand that my personal information will remain confidential to the researcher.
- I understand that my organisation will not be identified either directly or indirectly.
- I have had the opportunity to have questions answered to my satisfaction.

Print Name: ________________________________

Signature:___________________ Date: __________________

Phone Number:___________________

Email: _______________________________

APPENDIX E – EVALUATION PROTOCOL FORM FOR FRAMEWORK

Interview introduction

The evaluation interview is aimed to enhance the proposed integrated framework and provide a clear flow of information while analysing the components of the framework. The proposed framework is an output of this doctoral study that aims on developing a strategic framework for the adoption of industry 4.0 strategies in the UK infrastructure sector. The findings were the basis used for the development of the framework which included 21 semi-structured interviews that were conducted and a systematic literature review.

This interview aims to compile responses from yourself and fellow experts to assist the researcher in evaluating the framework that will consequently be used for implementing Industry 4.0 initiatives within the UK infrastructure sector. Without input from experts like yourself, the evaluation of the framework cannot be developed, hence please partake in the interview. The estimated duration of the interview is around 15 minutes.

To allow confidentiality and ambiguity, the answers you provide will be tagged with a distinctive code which can only be recognised by the researcher. The codes will be deposited on a computer which will be password secure where only the researcher will have access to it. The data that has been provided by yourself will further get destroyed once the research is completed. ethical approval has been granted for the research protocol by the University of Wolverhampton offering additional reassurance.

Aims and objectives.

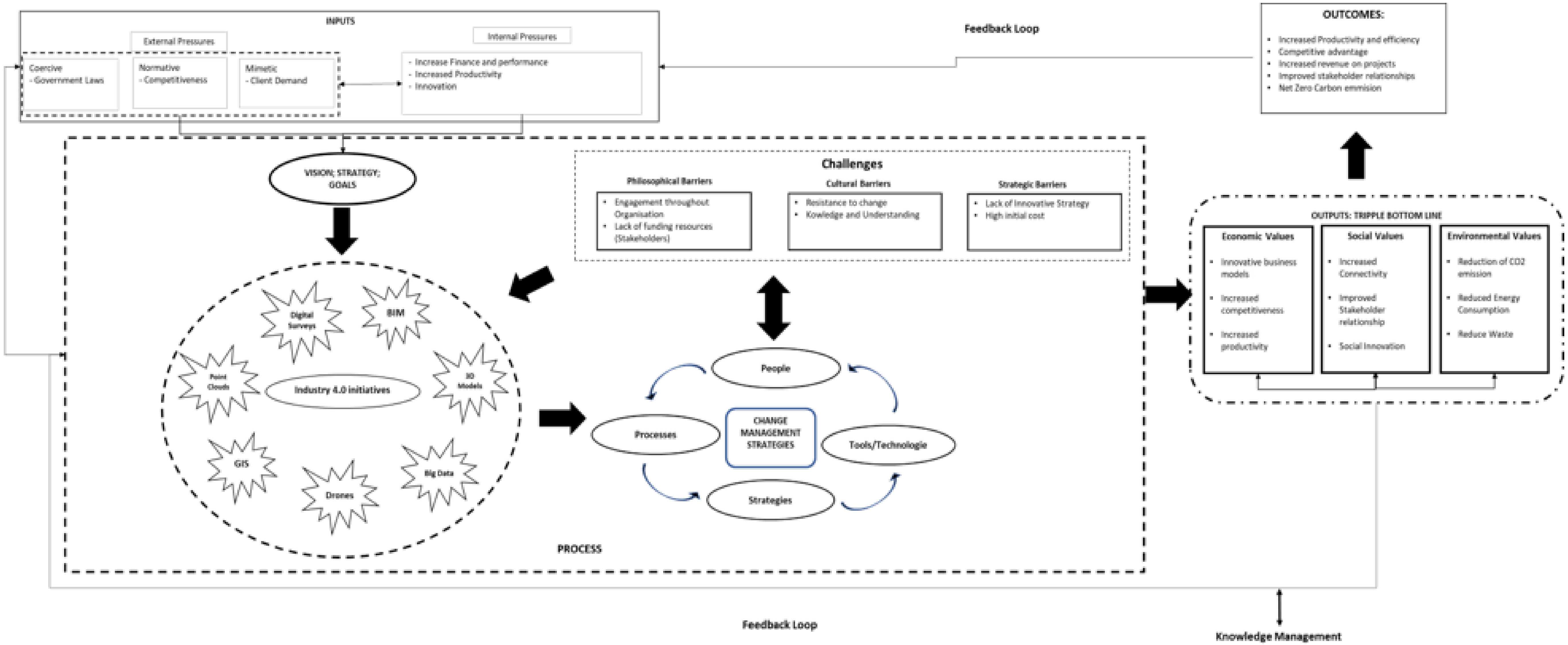
This research study aims to investigate the impact of Industry 4.9 strategies on organisations' competitiveness within the UK infrastructure sector.

The aim of this study was further broken down into more focused objectives to allow the general aim to be achieved. The set of objectives for the research is as follows:

1. To explore the prospect of industry 4.0 strategies in general and the UK infrastructure sector.
2. To investigate the key drivers for embracing Industry 4.0 strategies in the UK infrastructure sector.

3. To explore and understand the key Industry 4.0 strategies implemented in the infrastructure sector.
4. To investigate the challenges of adopting Industry 4.0 strategies in the infrastructure sector.
5. To investigate the key leading change strategies that have been adopted in the UK infrastructure sector to embrace Industry 4.0 concepts.
6. To explore the potential benefits of adopting Industry 4.0 strategies in the infrastructure sector.
7. To develop and evaluate the industry 4.0 business model framework. **Questions**

- In your opinion, what is the level of insight this is presented by the proposed framework?
- In your opinion, what is the level of comprehensiveness of the framework proposed?
- In your opinion, how is the workflow of the proposed framework presented?
- Are there any additional comments/recommendations concerning the framework you feel should be added/removed/amended?
- In your opinion, can you describe how useful the framework is to organisations within the UK infrastructure sector?



Arrow Style Link	Link Representation
	Processes links in framework
	Link of Stages preset in framework
	Loop of Changes to feed into each change process
	Two-way continuous feedback between actions

INTERVIEW FOR FRAMEWORK EVALUATION CONSENT FORM

Consent form

- I agree to partake in the research above and unreservedly give my consent.
- I recognize that this project will be performed in line with the “Interview introduction” described which I have been provided a copy of.
- It is my understanding that I can withdraw from the project at any given time, and I am not required to provide reasoning for the withdrawal.
- I give consent in participating in the interview led by the researcher.
- It is my understanding my personal information will be confidential only to the researcher.
- It is my understanding that my organisation will not be directly recognised or indirectly recognised through this study.
- I have been given the opportunity to raise questions which have been answered to my contentment.

Name: ________________________

Signature: __________________________ Date: ________________

APPENDIX F – READINESS TOOL EVALUATION PROTOCOL

This evaluation interview is aimed to evaluate and enhance the readiness tool that has been developed to ensure that the workflow and aspects are relevant to the UK infrastructure sector. The readiness tool that has been developed forms a part of this doctoral research which aims to develop an industry 4.0 readiness tool to support organisations within the UK infrastructure sector in implementing industry 4.0 initiatives. The readiness tool has been developed with the use of the findings outputted from 21 semi-structured interviews conducted for this research study.

This interview aims to compile responses from yourself and fellow experts to assist the researcher in evaluating the developed readiness tool that will consequently be used for implementing Industry 4.0 initiatives within the UK infrastructure sector. Without input from experts like yourself, the evaluation of the readiness tool cannot be developed, hence it is requested that you partake in the interview. The estimated duration of the interview is around 15 minutes.

To allow confidentiality and ambiguity, the answers you provide will be tagged with a distinctive code which can only be recognised by the researcher. The codes will be deposited on a computer which will be password secure where only the researcher will have access to it. The data that has been provided by yourself will further get destroyed once the research is completed. ethical approval has been granted for the research protocol by the University of Wolverhampton offering additional reassurance.

Aims and objectives.

This research study aims to investigate the impact of Industry 4.0 strategies on organisations' competitiveness within the UK infrastructure sector.

The aim of this study was further broken down into more focused objectives to allow the general aim to be achieved. The set of objectives for the research is as follows:

1. To explore the prospect of industry 4.0 strategies in general and the UK infrastructure sector.
2. To investigate the key drivers for embracing Industry 4.0 strategies in the UK infrastructure sector.
3. To explore and understand the key Industry 4.0 strategies implemented in the infrastructure sector.

4. To investigate the challenges of adopting Industry 4.0 strategies in the infrastructure sector.
5. To investigate the key leading change strategies that have been adopted in the UK infrastructure sector to embrace Industry 4.0 concepts.
6. To explore the potential benefits of adopting Industry 4.0 strategies in the infrastructure sector.
7. To develop and evaluate the industry 4.0 business model framework.

Questions

- In your opinion, what is the level of insight this is presented by the proposed readiness tool?
- In your opinion, what is the level of comprehensiveness of the readiness tool proposed?
- In your opinion, how is the workflow of the proposed readiness tool presented?
- Are there any additional comments/recommendations concerning the readiness tool you feel should be added/removed/amended?
- In your opinion, can you describe how useful the readiness tool is to organisations within the UK infrastructure sector?

Measure	Description
1	Not distinguished – never happens
2	Slightly distinguished – at times happens
3	Distinguished – occasionally happens
4	Very distinguished – frequently happens
5	Highly distinguished – always happens

Organisation Need: consists of the extent to which the organisations employees feel that there is a necessity for industry 4.0 initiatives						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	There are valid reasonings to implement industry 4.0 initiatives (e.g., government laws, clients' requirements)					
2	There are business requirements that need industry 4.0 initiatives to be implemented (e.g., competitiveness, stakeholder specifications)					
3	The reasons for implementing industry 4.0 initiatives (e.g., improving productivity, increasing efficiency)					
4	Resources are being invested in for industry 4.0 initiatives to be conducted efficiently (e.g., competent resources, technologies)					
5	The organisation has a good reason to adapt to industry 4.0 initiatives (e.g., economic value, social value)					
6	The reason for implementing Industry 4.0 initiatives has been made clear to me.					

The score for the organisation's need has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly about the need for industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisations feels somewhat that there is a need for industry 4.0 initiatives to be implemented.

- **18 – 13:** The member of the organisations feels there is a slight need for industry 4.0 initiatives to be implemented.
- **< 12:** The member of the organisation feels there is no need for industry 4.0 initiatives implementation.

<table>
<tr><td colspan="7">Organisations' willingness to change: consists of the extent to which the organisations are willing to change for industry 4.0 initiatives</td></tr>
<tr><td colspan="2" rowspan="2">Criterion</td><td colspan="5">Score</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>1</td><td>The organisation think that industry 4.0 initiatives implementation can benefit the organisation.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>Implementation of industry 4.0 initiatives will provide more efficient and effective processes for the organisation.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>The implementation of Industry 4.0 initiatives will better our everyday tasks as an organisation.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>The organisation is willing to gain knowledge and understanding of the new processes introduced by implementing industry 4.0 initiatives.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>Training and upskilling for industry 4.0 initiatives can and will be provided to upskill employees.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>The organisation will get the resources that are required for industry 4.0 initiatives implementation.</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

The score for the organisation's willingness to change has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that their organisation is willing to change for industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisations feels somewhat that their organisation is willing to change for industry 4.0 initiatives to be implemented.
- **18 – 13:** The member of the organisations feels there is a slight chance that their organisation is willing to change for industry 4.0 initiatives to be implemented.

- **< 12:** The member of the organisation feels there is no chance that their organisation is willing to change for industry 4.0 initiatives implementation.

Employees' willingness to change: consists of the extent to the employees are willing to change for industry 4.0 initiatives implementation						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	I think that industry 4.0 initiatives implementation can create personal benefits.					
2	Implementing industry 4.0 initiatives can allow the enhancement of my capabilities.					
3	I can gain future benefits through the implementation of Industry 4.0 initiatives in my organisation.					
4	I think I can gain advantages in my career if my organisations implement industry 4.0 initiatives.					
5	I am not in fear of my position and status in the organisation when it implements industry 4.0 initiatives.					
6	I think I have the capabilities to learn new ways of working and processes when my organisation implements industry 4.0 initiatives.					

The score for employees' willingness to change has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that they can benefit from industry 4.0 initiatives to be implemented.
- **24** – **19:** The member of the organisations feels somewhat that they can benefit from industry 4.0 initiatives to be implemented.
- **18** – **13:** The member of the organisations feels there is a slight chance that they can benefit from industry 4.0 initiatives being implemented.
- **< 12:** The member of the organisation feels there is no chance that they can benefit from industry 4.0 initiatives implementation.

Support from management: consists of the extent to which the members of the organisation feel that management within the organisation is dedicated to providing support Industry 4.0 initiatives implementation or otherwise.						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	Higher management in the organisation has been clear on the organisation implementing industry 4.0 initiatives.					
2	Higher management has been leading by example when it comes to industry 4.0 initiatives.					
3	The leaders in the organisation are committed to successfully implementing industry 4.0 initiatives.					
4	Higher management has been involved in processes and changes involved with industry 4.0 initiative implementation.					
5	The organisation has been providing the resources and training needed and higher management has been pushing upskilling for industry 4.0 implementation.					
6	Managers and leaders have communicated and encouraged the implementation of industry 4.0 initiatives within the organisation.					

The score for support from management has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that managers within the organisation are committed to supporting industry 4.0 initiatives to be implemented.
- **24** – **19:** The member of the organisation feels somewhat that managers within the organisation are committed to supporting industry 4.0 initiatives to be implemented.
- **18** – **13:** The member of the organisation feels there is minimal effort from managers within the organisation showing commitment to supporting industry 4.0 initiatives to be implemented.

- **< 12:** The member of the organisation feels there is no chance that managers within the organisation are committed to supporting industry 4.0 initiatives implementation.

Organisations productivity: consists of the extent to which the members of the organisation feel that their organisation would gain value from implementing industry 4.0 initiatives.						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	I think that the organisation can gain value from implementing Industry 4.0 initiatives.					
2	The organisation can save costs and be efficient through the implementation of Industry 4.0 initiatives.					
3	Stakeholder relationships with the organisation can be enhanced by implementing industry 4.0 initiatives.					
4	Overall productivity and efficiency can be enhanced with the implementation of Industry 4.0 initiatives.					
5	The organisation can be highly respected within the sector through industry 4.0 initiatives implementation.					
6	The organisation can save time on projects leading to gaining profit through the implementation Industry 4.0 initiatives.					

The score for organisations' productivity has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that their organisation will gain value Industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisations feels somewhat that their organisation will gain valuable industry 4.0 initiatives to be implemented.
- **18 – 13:** The member of the organisations feels there is a slight chance that their organisation will gain valuable industry 4.0 initiatives to be implemented.
- **< 12:** The member of the organisation feels there is no chance that their organisation will gain value Industry 4.0 initiatives implementation.

Organisations' willingness to invest: consists of the extent to which the members of the organisation feel that their organisation would invest in the necessary tools for implementing industry 4.0 initiatives.						
Criterion		**Score**				
		1	**2**	**3**	**4**	**5**
1	I think that the organisation can provide adequate training in implementing Industry 4.0 initiatives.					
2	I believe that the organisation will provide the technology required for the implementation of Industry 4.0 initiatives.					
3	The organisation can get the required licences for the entire supply chain when implementing Industry 4.0 initiatives.					
4	The organisation will invest in the necessary resources for the implementation of Industry 4.0 initiatives.					
5	The organisation can be trusted to support and provide any financial requirements for industry 4.0 initiatives implementation.					
6	The organisation will provide the tools needed to successfully adopt the implemented Industry 4.0 initiatives.					

The score for organisations' willingness to invest has been assessed by calculating the final score which has been allocated to each of the criteria above:

- **30 – 25:** The member of the organisation feels strongly that their organisation is willing to fully invest in industry 4.0 initiatives to be implemented.
- **24 – 19:** The member of the organisations feels somewhat that their organisation is willing to invest in industry 4.0 initiatives to be implemented.
- **18 – 13:** The member of the organisations feels there is a slight chance that their organisation is willing to invest in industry 4.0 initiatives to be implemented.

- **< 12:** The member of the organisation feels there is no chance that their organisation is willing to invest in industry 4.0 initiatives implementation.

Overall Score

- **150 – 125:** The organisation is extremely ready to implement industry 4.0 initiatives.
- **124 – 99:** The organisation is very ready for industry 4.0 initiatives implementation.
- **99 – 74:** The organisation is slightly ready to implement Industry 4.0 initiatives - < **73:** The organisation is not ready to implement industry 4.0 initiatives.