Artificial Intelligence technology in a portal frame structure measuring

by

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A thesis submitted in fulfilment of the requirements

For the degree of Master of Engineering

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New Zealand

February 2022

Abstract

Artificial intelligence technology, also known as AI, is a 21st-century great innovation and vastly solves many contemporary industry issues. For instance, in the medical industry, using Artificial intelligence to detect lung cancers and in the construction industry, AI can improve productivity and health safety by measuring structure application to build in Building information modelling.

The construction industry's productivity has not improved in the past three decades of overbudgeting, human errors, and fatality issues. The construction industry issues come across a wide range of hot topics such as health & safety, productivity, and economic-financial impacts, all related to the industry market's future growth and national GDP raises.

The digital solutions to information sharing platforms, assets management and field management can be seen as very popular in modern industries. Improving productivity and closing the supply chain gap exist in the construction industry that desperately needs to be addressed.

This thesis focuses on how a leading digital solution such as deep learning technology can apply to large objective measurements in the construction industry, which set a new benchmark for building structure measuring. In addition, the thesis also discusses the deep learning technology can impact the social economy with respect to utilising the unemployed population to present their surplus-value in the construction community and resolve supply chain issues.

However, AI technology also concerns the social-economic system as a potential risk in replacing human operators in many working areas. The research has a detailed discussion on this topic.

In addition, the adoption of deep learning technology will positively impact the supply chain in the Covid situation and bring hopes for post-pandemic supply chain recovery.

Lastly, the thesis presents the future view of artificial intelligence technology and its limitation to prove that it is friendly to secure human beings' future.

Acknowledgement

I would first like to take this opportunity to thank my thesis supervisor Dr. James Lim for his thoughtful advice. He consistently allowed this paper to be my own work but steered me in the right direction whenever they thought I needed it.

Also, I would like to express my sincere appreciation, to Dr. Bruce Sham for his expertise, thoughtful advice, and constant encouragement.

My sincere thanks go to my friend Mr. Robin Liu (CEO of the SCL group Ltd), who provided me with an opportunity to join his team as the portal frame project manager and supported me with his technical advice. Without his precious support, it would not be possible to conduct this research.

I must express my profound gratitude to my parents and to my wife for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis.

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1.1 Introduction

The construction industry background

The construction industry has been considered one of the most dangerous and slow productivity improvement industries globally. The technology investment in the global construction market, including R & D is only 10% of the entire building materials cost (Mckinsey Global Institute, 2017). The productivity of construction activities has remained unchanged for the last decades.

The construction industry has one of the lowest growth rates in productivity, where only contributed 1% growth rate over the last 20 years. Construction-related spending, which accounts for 13% of the world's GDP, was dragged down by slow-growth industry productivity. (Mckinsey Global Institute, 2017) The need for raising productivity in the construction industry has been discussed for long decades with minor achievements. The industry labour rates rapid growth, which causes more financial negative impact on the asset owners and contractors. Hence, BIM is one of the leading solutions in the industry to solve productivity issues and improve information management for assets owners (Mckinsey Global Institute, 2017).

Many technologies are available in the construction industry to improve communication and productivity. Typical iconic technology in modern days digital eras such as Artificial intelligence- A.I., big data, Internet of things-IoT, Virtual reality-V.R., 5G, and digital integrations play a critical role in reducing risks of workers' injury and improving the productivity of the construction activities. BIM Building information modelling is a cutting-edge management platform that transforms the building construction industry from traditional "manual work" into the digital era. BIM is not only referring to specific software but a collective system in managing building construction activities. BIM also can be regarded as one of the leading players in Smart

Construction strategy in developed countries. Digital transformation in constructions can be traced back to recent years' activities.

In comparison to other developed countries, New Zealand constructions industry contributes 6% of GDP to the entire nation, and the industry can be seen as having poor productivity, high materials cost and high labour cost (STATS, 2020). New Zealand construction industry supply chain is fragmented and characterised by poor communication resulting in a misalignment of needs among materials supply chain stakeholders.

The population growth drives New Zealand housing market demand. Over the next ten years, New Zealand has more than $300 billion of housing, building and infrastructure needs. However, poverty rates in New Zealand have increased 10%, and the unemployment rate has been very healthy in 2012 since which remains at 4% (STATS, 2020). The Covid pandemic situation slows down migrants to come into New Zealand, which improves unemployment rates. However, the house labour force still has forces remain unemployed, and temporary employment contracts remain 10% of the employed population. How to utilise the unemployed population in the nation and generate more value to the community becomes one of the critical factors for New Zealand to come out of the pandemic economic situation.

Productivity related to the supply chain topic is also a significant concern affecting construction industry development. According to Mackenzie's report, every 5% productivity lift could save 1.5 billion dollars per year. That is equivalent to delivering another project scale-like Waterview tunnel.

Tylor defines cultural attributes as critical factors that determine the economic outcome. Three main factors determine the success of a country's economy, technology, system and culture. Rarely do economy researchers spend their efforts defining cultural attributes to the economic outcome (Tylor E, 1871).

1.2 State of the problem

An ideal roofing structure design of portal frame requires seismic compliances and installation details matching design drawings. The Portal frame industry has long existed in New Zealand and the rest of the world. Roofing structure measuring application in the portal frame structure is always a popular topic related to health and safety risk, accuracy, and productivity. By far, this application can only be measured by the workforce manually with a traditional tape measure or sophisticated surveying machines such as the total station and 3D scanner. Either way creates the risks of installers are falling off height incidents or running on high operational costs with poor accuracy. The marginal errors of accuracy from structure engineers design to actual installation can be varied from 20% with benchmark installers to 40% with inexperienced or rookie installers (Roofing COP, 2012). The construction labour shortage has become a severe contributor to slow down the economic growth since the Covid pandemic, and the portal frame roofing industry has been affected by the labour shortage, which creates 10-20% cost variance to the developer and main contractors.

Portal frame roofing system stability is not limited to the stressed skin but extended to the portal frame structure integrity in the long term. Roof systems, however, are consistently evolving, often leaving existing standards out-of-date. The typical connection detail for purlin to rafter connection includes C or Z purlins connected to the rafters through a web cleat. Such an arrangement has relatively low stiffness against shear deformation. On the other hand, modern top-hat shaped purlins can simplify the connection detail, act reasonably in carrying in-plane bending, improve purlin to rafter connection flexibility, and increase the diaphragm stiffness.

Generally, roof structures can fall into one of the following categories:

- Single skin roofs comprising one layer of metal cladding,

- Built-up roofs comprising liner tray, insulation layer and outer watertight panel,

- Composite panels manufactured from inner liner and outer sheeting profile with the core of insulation foam between the two layers(Roofing COP, 2012).

The following factors, such as human errors and safety set up, cause the installation of roofing structure inaccuracy and low productivity. The portal frame structures installation processes require concrete structure and steel beam installation. Surveying processes is a critical process in the entire foundation layout. In New Zealand, manual surveying processes are still operating in the last few decades. Data collection from surveying companies can be varied. It is very common to observe that the majority of portal frame structure fabricating processes are completed in the medium or small engineering shops in New Zealand. Therefore, manual welding and inaccurate fabricating operations prior to the site's delivery. Installing portal frame into the concrete foundation in using hold down anchor bolts such as high strength expansion safety anchor can create various levelling issues, which is due to the nature of expansion anchors require specific torque to set the anchor to the appropriate settings in order to generate seismic and dynamic loadings in both tension and shear. Alternatively, cast in anchor fixings design shall be used in the concrete foundation for the portal frame base collaborative process. Disadvantages of using cast-in anchor design require a high level of collaboration between steel installers and design engineers. Common issues of portal frame joint base do not match cast in anchor set out who is commonly seen on sites. Bracing installation requires bolts connections setting to the specific design torque in order to achieve best design practice. Any under torque or over-torque can result in joints of structures unmatched by the drawing design details during steel erections.

On-site measuring of portal frame structures to determine the elements of the roofing structure become essential rather than the artificial working process from the offsite offices. On-site measuring requires labour to climb up to the top of the portal frame to measure all structure elements in order to determine the roofing elements such as roofing sheets and gutters size. Data collection generally takes 3-4 days to send to the manufacturers to cut into the size and deliver to the sites. The measuring data was collected on-site but only considered estimated data for the roofing installers. Resize roofing sheets and gutters are generally seen as standard practice on sites due to portal frame structures natures.

Due to Covid pandemic travel restrictions, the New Zealand domestic labour shortfall also creates pressure on the construction industry, especially in the portal frame steel industry. The industry cannot afford further damages to the supply chain delay or the installers injury or fatality related to health and safety.

1.3 Research gap

The most application of deep learning in computer vision focuses on computer vision tasks, including image classification, object detection, and image segmentation. The technology is rarely in use in the construction industry, which is due to the low productivity of the industry mentioned earlier in the article. Roofing structures has many issues themselves in cold-formed structures (Lim et al,. 2005). The concept of using artificial intelligence in large objective measuring remains a research gap due to the industry investment in innovative technology in resolving current industry issues. In addition, the construction industry is vaguely differentiated Lidar technology to artificial intelligence imaging technology.

This research focuses on concept approved novel of using deep learning technology to advance the sizeable objective measurement to improve the industry productivity and accuracy.

Lastly, the artificial intelligence deep learning in the research initiates a new digital era in the near future for construction applications such as structure inspections, passive fire solutions and coordinating supply chain to reduce construction lead time and productivity. The pandemic period requires more skilful tradespeople to complete the current and future projects where artificial intelligence can lower the barriers for the construction workforce to support the market in the labour shortfall aspect.

1.4 Thesis objectives

This research study is aimed to develop a concept of a novel artificial intelligence deep learning technology to enhance the mobile device, and portal frame structure codes practice knowledge to measure significant objectives to deliver the system to achieve the roofing structure measuring outcome.

This research conducts three layers research study, including technical competence, social economy and social culture of applying artificial intelligence technology in image application to prove the concept of using portal frame roofing structure measurement. The research is also set the foundation for future study in using artificial intelligence deep learning advanced technology applied to the civil engineering applications in the construction industry. The impact of applying artificial intelligence deep learning advanced technology to the construction industry can bring economic benefits by improving the supply chain in Covid pandemic periods and setting the new standards of collaborations between human beings and machines in the construction industry in the endemic period.

1.5 Background:

1.5.1 Market analysis:

The size of global construction market technology investment, including R & D, is only 10% of the entire building materials cost. Productivity has remained unchanged for the last decades (ICE, 2019). Covid pandemic hit in the year 2000 shook the construction industry in an unpredictable direction. The Covid pandemic impacts the economy with labour shortage and materials shortage immediately adding side effects to the industry developer such as cost increase and project delay. Before the pandemic, poor project planning of most New Zealand construction industry makes the entire industry supply chain relying on offshore resources vulnerable and fragile during pandemic periods.

The New Zealand roofing industry has had a booming period since 2009. The economic recession brings the opportunity to reset the construction industry market and leaves the market to recalibrate its resource to allow the key players in the New Zealand market to invest in technology innovation. Steel roofing is a rising industry that plays a crucial role in the majority of the commercial property market. Steel roofing manufacturers play a critical role in supplying the components to the steel structure building, including portal frame buildings. The supply chain plays a crucial role to ensure the roofing structure installation completes in a planned schedule.

Health and safety are like a virus that remains silently surrounding us and prevention. In New Zealand, falling from height is one of the top risks in the construction industry. The roofing industry is one of the top risks of injury and fatality trades in the industry.

1.5.2 Supply chain literature review

Supply chain

The New Zealand construction industry is diverse and fragmented, has low productivity and proliferation of different industry associations endorsing their sources (BCSPP 2011)

High cost, low productivity, poor communications to the homeowners, and poor building quality are leading characteristics for the New Zealand residential construction industry. (BCSPP, 2011; CHRANZ, 2011; Hinton, 2011) The research of the New Zealand construction cost breakdown Table 1.1 indicates that materials and labour costs have over 80% cost share of entire house construction costs. Traditional house construction in New Zealand faces challenges in a rapidly growing population environment. The industry is seeking an alternative solution to resolve housing crisis issues. Prefabrication construction technology has proven success records in other countries like Japan and Sweden to solve the housing shortage issue.

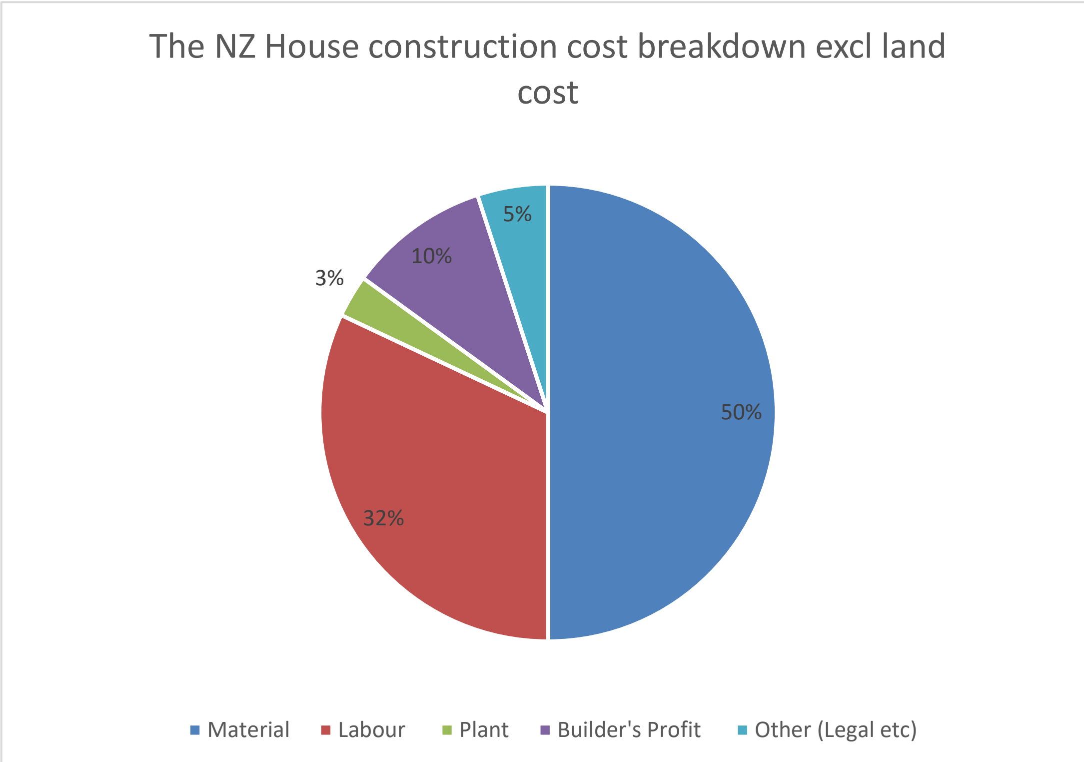

Table 1.1 Buckett N.R. (2014) Advanced residential construction techniques-opportunities and implications for New Zealand. BRANZ

They are connecting to the global market with innovative technology. Manufacturing business costs in New Zealand can be very challenging in the current economic environment. High tax and relatively high labour costs have been significant challenges for the New Zealand prefabricated business development. The New Zealand prefab house is less than 2% in full 100% completed by prefabricated elements. The results indicate that the New Zealand manufacturing industry has a low contribution to prefabrication. The issue indicates that the New Zealand industry contribution to the Prefabricated business is 32% compared to Sweden 85% in a detached house, and Japanese prefabrication house has 15% in every million new houses in the market. (Steinhardt, D; Manley, K; Bildsten, L; Widen, K. 2020). All industry participants need to make significant changes.

Compared to Japan and Sweden, the New Zealand building industry has a low degree of industry collaboration, resulting in a low growth rate of the building industry innovation and productivity (Steinhardt, D; Manley, K; Bildsten, L; Widen, K. 2020). On the other hand, Japan and Sweden shares synergies of a high degree of local industry collaboration, which led to industry innovation and productivity improved dramatically over the last century. The Low Cost and high quality of prefabricated house products outcomes of industry collaboration. The eHomes collaborate with leading global anchor suppliers. Hilti a leading construction supplier created an innovative panel installation system that overcomes the issues of slight edge and high capacity tension load demand for bottom plate application. Eight days production lead time to complete a two storeys house in the manufacture also reflects the high productivity achieved from the skilled labour and well-equipped manufacture.

3D printing technology in the construction industry is the solution to minimise human errors and create the potential for completing the customised prefab product in the same production line. The technology hinted that the portal frame building structure could be manufactured using 3D printing technology.

Because SCM implementation in the construction industry has been scattered and partial so far, this review paper intended to give an overview of the context and focus of previous supply chain studies set within a construction context and provide a reference guide for further research; the authors intend to update and extend this literature review. Hence, any provision of information related to construction supply chains is welcome and highly appreciated.

One of the most significant findings from our literature analysis has been the relative lack of theoretical work in this field compared to empirical-based studies. Further research could compare the fit of supply chain management strategies with existing construction management strategies. In particular, due to the fragility of many construction systems, future studies may shift particular focus to the role of supply chain management strategies in achieving construction sustainability at the project level and expand the focus to supply chain management strategies used in construction systems.

1.5.3 Population demographics in related to supply chain

The New Zealand nation has a 4.87 million population by November 2021, which is spreading out in 263,310 square kilometres of landscape(Stats 2021). The population density is relatively tiny as 18/km², compared to Monaco 19,361/ km² and Singapore 8,019/ km². Today, the population density across New Zealand is imbalanced as three in four people live in the North Island, and one in four people live in the South Island. Even worse, Auckland has almost half of the national population as 1.46 million people currently reside in the local, ranging up to 18,000 people per square kilometre in Central Auckland (Stats 2021). Supply chain management in the construction industry has to cover high transportation costs and charges, depending on infrastructure readiness, population density and forecasting plan. Hence, there is demand on using advanced technology that can speed up the processes in providing accurate details in the supply chain management in order to reduce the cost and waiting time of receiving information.

1.5.4 Covid 19 impacts on supply chain

The Covid 19 pandemic hits globally in February 2020 and impacts the global supply chain in both labour force and materials. Many countries, including New Zealand, initiate domestic lockdown and international travel restrictions with isolation policies and materials manufacturers and supplies face labour shortages to extend their general production lead time in completion of the products. Global shipping, including any types of transportation such as airfreight, sea freight and rail freight, has to increase the price and extend the lead time to cover the general operations during the pandemic. Even worse, the New Zealand construction materials heavily rely on overseas supplies (Aday S, Aday MS, 2020). 90% of building products sold in New Zealand either imported or contains imported components from overseas, which is not easily replaced by domestic supply. Hence, a forecasting plan becomes critical for most New Zealand construction project supply chains during the pandemic. Roofing supply in the portal frame structure is a typical building structure that requires site measurement to send critical data to the manufacturer for further materials completion.

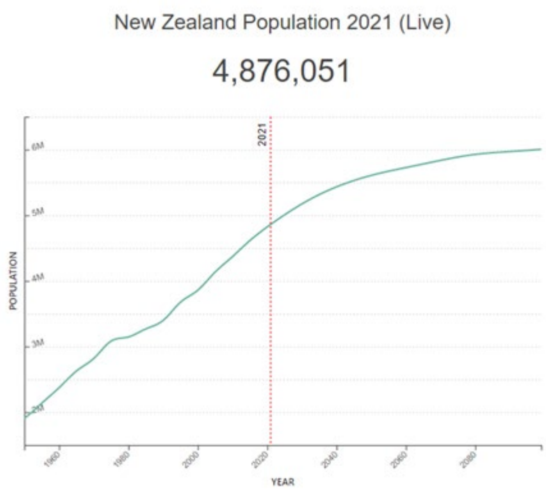

Figure 1.1 NZ population growth and distribution (Stats NZ, 2021)

Chapter 2

2.1 The origin of artificial intelligence

2.1.1 Hilbert's century questions lead to computer invention

Many theories of artificial intelligence deep learning technology evolution paths have been developed in the past decades, based on what researchers found. One of the leading theories of evolution paths is well known and recognised by Artificial intelligence top researchers is based on complexity systems. Complexity system (Mitchell, M 2001) states all complexity activities are made of logical interactions with simple actions to feedback loops to change the system. Many examples of wildlife complexity activity such as ants' organisational structure and firefly illusions in the cave proved that complexity is made of simple activities. Complexity theory emphasises interactions and the accompanying feedback loops that constantly change systems. Machine learning of artificial intelligence is one of the best examples of complexity theory outcomes. The world-renowned professor Melanie Mitchell is one of the leading experts in this leading field. The modern problem requires a modern solution. Complexity activities evolution requires a logical and scientific solution to explain it, and mathematics becomes the leading solution. The great invention begins with three critical questions out of 23 problems were raised by German leading mathematics professor David Hilbert in the Paris Congress of Mathematics in 1900. The 23 problems are known as "Century Ask" in the mathematics world(Wilfried, S 2013).

1st problem The continuum hypothesis (that is, there is no set whose cardinality is strictly between that of the integers and that of the real numbers)

2nd problem Prove that the axioms of arithmetic are consistent.

3rd Given any two Polyhedra of equal volume, is it always possible to cut the first into finitely many Polyhedral pieces that can be reassembled to yield the second?

Mathematic always plays a critical role in majority technology evolution, especially in Artificial intelligence origin development. Three-century questions lead to the first computer invention and the first artificial intelligence machine.

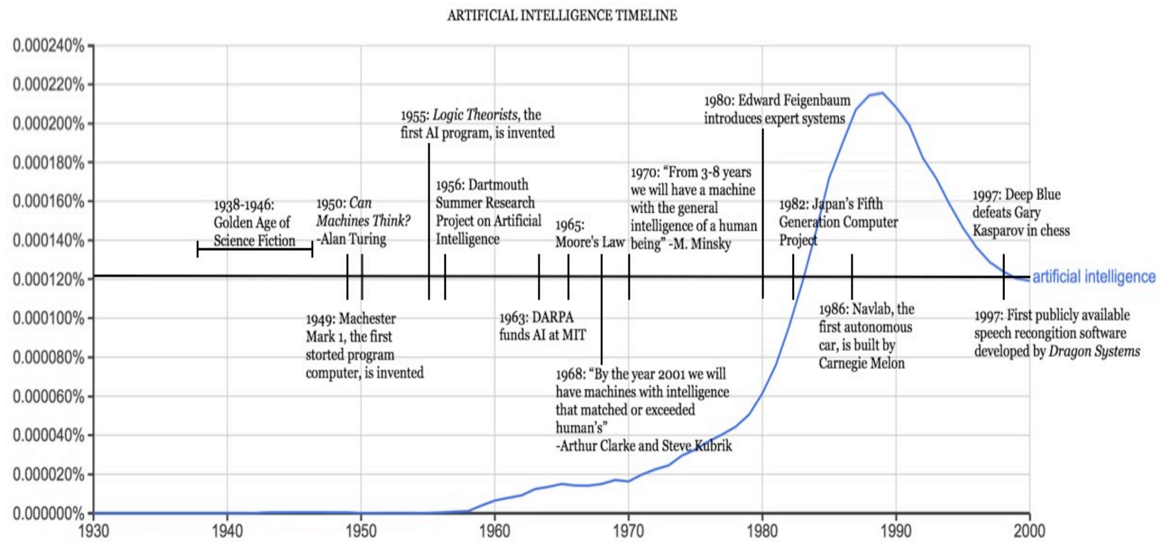

Fig 2.1 AI development history (Harvard, 2022)

The first two mathematics century questions were resolved by Kurt Friedrich Gödel when Gödel delivered the paper called "On Formally Undecidable Propositions of Principia Mathematica and Related Systems" during the Second Conference on the Epistemology of the Exact Sciences in 1930. Gödel's theorems ended up half-century puzzles from Hilbert's first two-century questions, which are that:

If a (logical or axiomatic formal) system is omega-consistent, it cannot be syntactically complete.

The consistency of axioms cannot be proved within their system (Dawson, 1997:68).

The theorems research work was initiated by Gottlob Frege and culminated in Principia Mathematica and Hilbert's formalism, who found a set of axioms sufficient for all mathematics. In hindsight, Gödel' basic idea at the heart of the incompleteness theorem is not complicated, and he constructed a formula that claims that it is unprovable in a given formal system (Godel, K, 1932). The assumption states that if it were provable, it would be false. Thus, there always be at least one true but unprovable statement. There is a formula that is true of arithmetic for any computably enumerable set of axioms for arithmetic but which is not provable in that system. To make this precise, however, Gödel initiates a process known as Gödel numbering to encode statements, proofs, and the concept of probability.

Gödel refuted the finite-valuedness of intuitionistic logic in paper Zum intuitionistischen Aussagenkalkül in 1932 (Godel, K, 1932). The paper includes significant theory discoveries in mathematics history called Gödel–Dummett intermediate logic. Hilbert's first two-century question was resolved by Gödel, which led to the first generation computer foundation formula until Dr Turing resolved the third-century question. Turing machine invention resolved the third question raised by Professor David Hilbert.

2.1.2 Turing machines origins

Turing published the paper called "On Computable Numbers, with an Application to the Entscheidungs problem" in 1936 which the paper focused on reformulating limits of proof and computation on Kurt Gödel's 1931 results and replace Gödel's universal arithmetic-based formal language with the formal and simple hypothetical devices called Turing machines.

Turing initiated a universal computing machine program after the leading German mathematician David Hilbert raised the Entscheidungs problem in 1928 (Hilbert, D 1928). The program created a machine that could perform any conceivable mathematical computation if it were representable as an algorithm. The great discovery solved the third-century problem as Turing proved that there was no solution to the decision problem by first showing that the halting problem for Turing machines is undecidable: it is not possible to decide algorithmically whether a Turing machine could ever halt. This paper has been called "easily the most influential math paper in history" (Turing, A 1936).

The Turing machine's invention marks the first era of the logical computer program, which leads to Artificial intelligence from the conceptual stage to practical performance. Turing machine decodes all German allies secret codes, which contributes significantly valuable information to anti-Nazi allies. Following Turing machine invention, many researchers and their projects have rapidly developed in the following decades and contributed to the current AI technology revolutionising development, imaging scan and analysing area.

2.1.3 Turing Test

Turing test, a standard for a machine to be called "intelligent" A computer could be said to "think" if a human interrogator could not tell it apart, through conversation, from a human being. In Dr Turing's philosopher quote: Rather than building a program to simulate the adult mind, it would be better instead to produce a simpler one to simulate a child's mind and then to subject it to a course of education."

A classic and essential part of the Turing test called the Imitation Game, also known as IG, defined the machine's thinking ability (Turing, 1950, p. 442, emphasis added). The game design involves party A, a man, Party B, a woman, and an interrogator whose gender is irrelevant. This game aims to identify which of the other parties is the woman, while the objective of both the man and woman is to convince the interrogator that he or she is the woman and the other is not. The situation can be explained in Figure 2.2.

Turing defined the IG; Turing defends the choice of replacing the question "Can machines think?" with "Can machines play the imitation game?". The new problem focuses on intellectual capacities and does not let physical aspects interfere with granting intelligence to an entity. Nor does it limit thinking to specific tasks like playing chess or solving puzzles since the question-and-answer method is suitable to introduce any topic imaginably (Turing, A 1950).

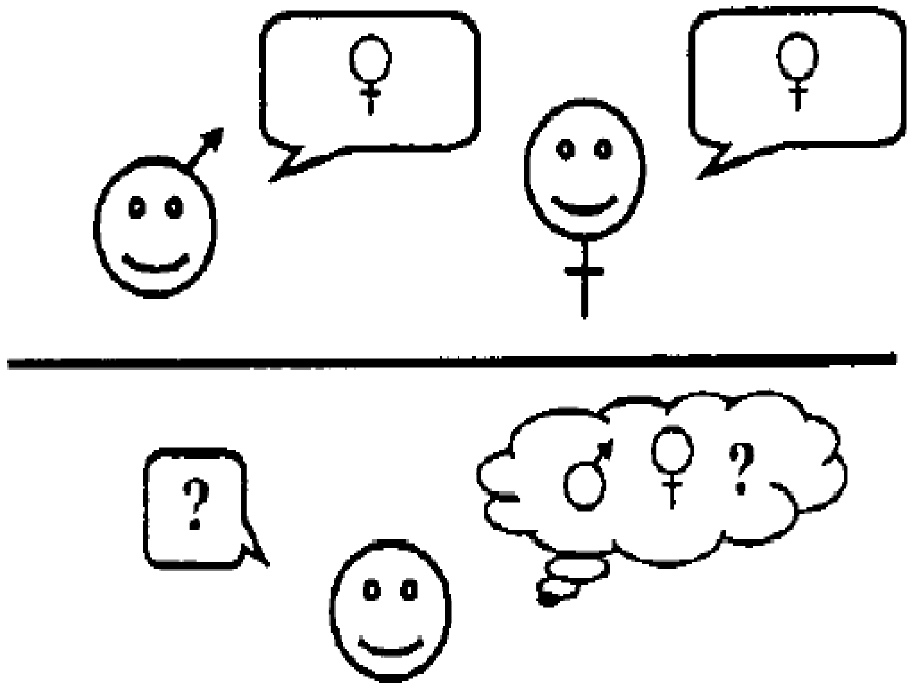

Fig 2.2 Imitation Game (Turing, A. 1950)

Von Neumann is previously known as Jon Neumann, who contributes enormous efforts and time to continue research in proving Hilbert's century questions. Von Neumann's research proves that the axiomatic system of the theory of sets is possible to avoid the conflicts that may arise to the earlier systems, and the research work sets the foundation for mathematics without considering its consistency. Von Neumann's research work also adds stronger axioms that could be used to solve a broader class of theorems with/without definitive answers (Neumann, J. 1962).

The research work of proving the consistency of first-order arithmetic was continued by von Neumann, who was inspired by Ackermann's work. The key findings from von Neumann's research proved that the consistency of a fragment of arithmetic of natural numbers is positive, and the general proof of the theory can apply to the other consistency of classical mathematics methods (Neumann, J 1927).

Kurt Gödel announced his first theorem of incompleteness in September 1930, which delivered a firm negative answer to whether the century questions was definitive. In addition, the usual axiomatic system is incomplete which the research work needs to carry on without proving every truth expressible in their language. Moreover, the research work also addressed that every consistent extension of these systems remains incomplete (Godel, K, 1932).

2.1.4 Complexity theory

The complexity theory leads to artificial intelligence original fundamental base.

A "complex system" is a group or organisation made up of many interacting parts. Archetypal complex systems include the global climate, economies, ant colonies, and immune systems. In such systems, the individual parts—called "components" or "agents"—and the interactions between them often lead to large-scale behaviours which are not easily predicted from a knowledge only of the behaviour of the individual agents. Such collective effects are called "emergent" behaviours. Examples of emergent behaviours include short and long-term climate changes, price fluctuations in markets, foraging and building by ants, and the ability of immune systems to distinguish "self" from "other" and to protect the former and eradicate the latter (Mitchell, M 2001).

The artificial intelligence deep learning neural networks are based on the complexity theory with complex neural networks structure. The system forms all foundations on how artificial intelligence deep learning thinks human brains and sets the foundation on continuous learning ability fast enough to adapt to a rapidly changing environment. IBM Deep Blue is a classic physics neural network outcome of the complexity theory. Jon Neumann is the leading scientist in developing the theory into practice. Below Fig 2.3 presents the differences between machine learning and Chaos model in practice.

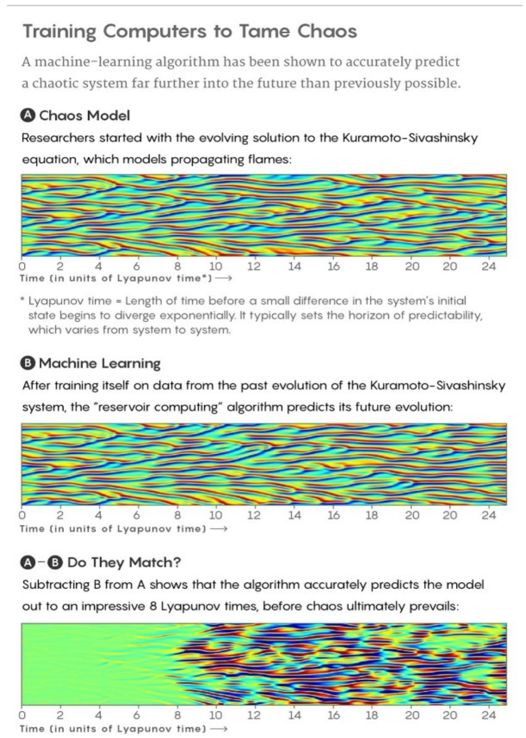

Fig 2.3 Chaos model vs machine learning (Kelly,L. 2022)

2.1.5 Chaotic dynamical system

Chaos theory is an interdisciplinary branch of mathematics focusing on the study of chaos: dynamical systems whose random states of disorder and irregularities are governed by underlying patterns and deterministic laws that are highly sensitive to initial conditions. Chaos theory states that there are underlying patterns, interconnectedness, constant feedback loops, repetition, self-similarity, fractals, and self-organisation within the apparent randomness of complex, chaotic systems (Chaos theory, 2019). The butterfly effect, an underlying principle of chaos, describes how a slight change in one state of a deterministic nonlinear system can result in significant differences in a later state. A metaphor for this behaviour is that a butterfly flapping its wings in Brazil can cause a tornado in Texas (Boeing, G 2015).

The butterfly effect can also apply to the measurement application where minor differences created in initial conditions due to measurement errors or rounding errors in numerical computation can extend to significant widely outcomes in a dynamical system (Weisstein, E, 2019). For instance, the space shuttle landing requires accurate calculations, a rounding error resulting from the space shuttles failing to land on the earth. The future behaviour prediction follows a unique evolution and is determined by initial conditions without any random elements interfering. This behaviour is known as deterministic chaos or simply chaos. Edward Lorenz summarised the theory as:

Chaos: When the present determines the future, the approximate present does not approximately determine the future.

Chaotic behaviour exists in many natural systems, including fluid flow, heartbeat irregularities, weather and climate. It also occurs spontaneously in some systems with artificial components, such as the stock market and road traffic. This behaviour can be studied by analysing a chaotic mathematical model or analytical techniques such as recurrence plots and Poincaré maps (Poincaré, J, 2017). Chaos theory has applications in various disciplines, including meteorology, anthropology, sociology, environmental science, computer science, engineering, economics, ecology, pandemic crisis management, philosophy and jazz music. The theory formed the basis for such fields of study as complex dynamical systems, edge of chaos theory, and self-assembly processes (Boeing, G 2015).

The Feigenbaum constants set the foundation for expressing ratios in a bifurcation diagram for a nonlinear map, which significantly contributes to mathematics field study. The formulas are named after the physicist Mitchell J. Feigenbaum (Feigenbaum, M. J. 1976).

2.2 The butterfly effect

The butterfly effect represents one of the leading research fields of Chaos theory which can be defined as a tiny marginal change from sets of input data that can lead to significant changes in outcomes resulting from the output (Weisstein, E, 2019).

2.2.1 Evolution algorithm

The evolutionary algorithm, also known as EA, is a subset of evolutionary computation, a generic population-based metaheuristic optimisation algorithm. An EA uses mechanisms inspired by biological evolution, such as reproduction, mutation, recombination, and selection (Vikhar, P. A. 2016). EA can apply to resolve many complex problems such as construction project personnel management which can identify the role of individuals in a large complex construction project. The performance of an individual determines the quality of the solutions.

Evolutionary algorithms usually perform approximating solutions to the majority of types of problems. Ideally, the algorithm does not assume the data but applies to biological evolution modelling, which is generally limited to explorations of microevolutionary processes. Practically, EA plays a prohibiting factor in a computational complexity problem. The leading cause of this process is that fitness function evaluation is the solution to overcome this difficulty. However, there may be no direct link between algorithm complexity and problem complexity.

Any advanced technology needs a defending system to ensure the system data is fully protected. Data encryption requires a complex and sophisticated design system to protect data privacy which leads us to fundamental Chaos theory.

2.3 Artificial intelligence evolutionary application- measuring

2.3.1 Measure theory

As previously mentioned in this research article, artificial intelligence technology is based on mathematics, and mathematics applies to the measure theory. The measure is based on a fundamental concept of probability theory. Measures define as a mathematical abstraction such as mass, length, area, volume, probability of events or even electrical charges (Fremlin, D. H. 2010). These seemingly distinct concepts are innately very similar and may, in many cases, be treated as mathematically indistinguishable. Far-reaching generalisations of measure are widely used in quantum physics and physics.

Measuring theory was not fully recognised as a branch of mathematics until the late 19th century when Ancient Greece Archimedes tried to calculate the area of the circle. Émile Borel, Henri Lebesgue, Johann Radon, Constantin Carathéodory, and Maurice Fréchet laid modern measure theory foundations (Rao, M. M. 2012).

Von Neumann plays a significant role in the evolutionary development of measure theory where he defines: "problem of measure" for an n-dimensional Euclidean space Rn may be stated as: "does there exist a positive, normalised, invariant, and additive set function on the class of all subsets of Rn?" Later, Felix Hausdorff and Stefan Banach proved that probability theory is related to the measure problem. The work indicates that positive measure solution shall be met when n = 1 or n = 2, and other cases can perform negative solution due to the Banach–Tarski paradox (Halmos, P, R. 1958). However, Von Neumann's work argued Felix Hausdorff and Stefan Banach's outcome and raised a new theory that the "problem is essentially group-theoretic in character": the existence of a measure could be determined by looking at the properties of the transformation group of the given space (Neumann, J. 1929). Von Neumann proved that a negative solution for higher dimensions is feasible where space dimensions = two from solvable Euclidean group but no solution to higher space dimensions. A positive solution can be resolved when the space dimension is applied under two or equals two. "Thus, according to Von

Neumann, it is the change of group that makes a difference, not the change of space (Halmos, P, R. 1958)."

Von Neumann publishes many papers that include many evolutionary measurement methods considered even more significant than the results. One of the significant discoveries from Von Neumann later years is dimension theory in algebras of operators, which used results on equivalence by finite decomposition and reformulated the problem of measure in terms of functions. Von Neumann made significant contributions to measure theory where Haar's questions of the existence of algebra of all bounded functions were resolved by proving "a complete system of representatives of the classes of almost everywhere-equal measurable bounded functions". The discoveries from Von Neumann set the new era for future research work in algebraic aspects of the problem (Ionescu T, A; Ionescu T, C. 1969).

2.3.2 Artificial intelligence in measuring theory

Our ancestors created a very original "algorithm" in calculating estimated foot length, which presented in Fig 2.4. This is the very first mean calculation in estimating length. The formula is relatively simple in using aggregate size divided 16 people to estimate "1 foot". Later the formula was improved by ignoring the two shortest and longest feet (Chabert, J, L 1999).

Fig 2.4 Greek “algorithm” origin (Chabert, J, L 1999)

Artificial intelligence deep learning technology has three primary learning methodologies: self-supervised learning, semi self-supervised learning, and unsupervised learning.

Deep learning technology has three principal learning methodologies: supervised, semi-supervised, and unsupervised.

Unsupervised learning, self-supervised learning leverages unlabelled data to provide supervision in training, such as by predicting some withheld part of the data using other parts. For text, we can train models to "fill in the blanks" by predicting randomly masked words using their surrounding words (contexts) in big corpora without any labelling effort (Devlin et al., 2018)! For images, the research can implement train models to tell the relative position between two cropped regions of the same image (Doersch et al., 2015). In these two examples of self-supervised learning, training models to predict possible words and relative positions are both classification tasks from supervised learning.

Jon Neumann did not develop artificial intelligence terminology and Alan Turing at the beginning of 1950 even they were recognised as the father of the artificial intelligence technology behind the scenes. The computer era had a significant transition from manual writing calculation to decimal logic and machine binary logic, which led to later computation architecture formalisation. Turing test also proves machines can think.

Summary:

Artificial intelligence technology has a long history of proving the machine can "think". Many great researchers such as Turing and Von Neumann made significant discoveries in AI evolution development. The complex theory is also critical in igniting the starlight for deep learning technology to follow the laws of nature. The Turing test is a remarkable study that proves the machine can think and resolve many complex problems during the second world war. The foundation and research findings are still being used in today's research.

Chapter 3

3.1 Research Methodology

3.1.1 Proof of concepts

For the purpose of exploring possibilities in using deep learning technology in measuring objectives, three conditions shall meet be met from the concept.

1. Measuring objectives is based on probability theories.

2. Artificial intelligence deep learning algorithm is based on probability theories.

3. Artificial intelligence deep learning algorithm can adapt its analytical calculus to measure objectives is a fundamental mathematics question.

3.1.2 measuring theory is based on probability theory foundations.

Probability theory refers to a branch of mathematics concerned with analysing random phenomena. The outcome of a random event cannot be determined before it occurs, but it may be any one of several possible outcomes. The actual outcome is considered to be determined by chance (Olav, K. 2002).

The measure is an extension of probability theory which study leads to many measurements such as length, area, and volume in our daily life. Below Figure 3.1 is a typical example of using intuition measures length and area measurement (Luce, R; Narens, L. 1987). The measurement is based on a combination of two or more subsections and subareas to estimate the length and areas of the entire objective (Weaver, N. 2013). However, the concept of measure could not be genuine if subsections and subareas are disjoint and overlap each other. The conclusion of measure outcome can be summarised as a function; when the input is a section, it outputs a length when the input is a shape, it outputs an area so applies to infinite geometrical objectives referred to as sigma additivity (Edward, B.1992).

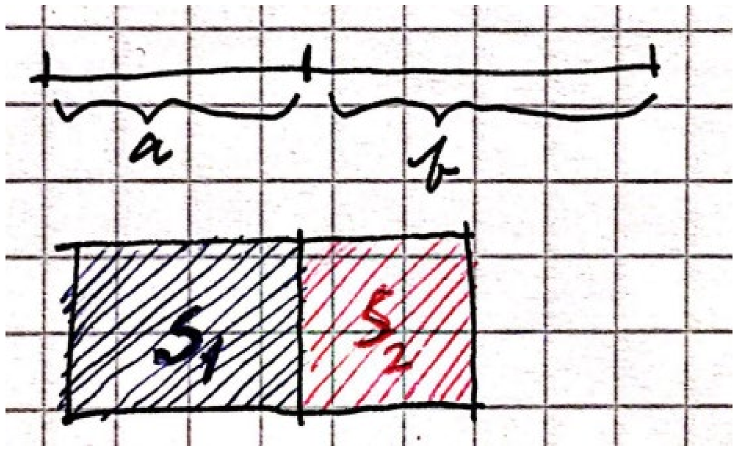

Fig 3.1 Intuition of measure (Luce, R; Narens, L. 1987)

As mentioned in this research thesis, artificial intelligence technology is based on mathematics probability theory, so the probability theory also applies to the measure. The measure is based on a fundamental concept of probability theory (Neyman, J. 1937). Measures define as a mathematical abstraction such as mass, length, area, volume, probability of events or even electrical charges. These seemingly distinct concepts are innately very similar and may, in many cases, be treated as mathematically indistinguishable. Far-reaching generalisations of measure are widely used in quantum physics and physics (Bogachev, V. I. 2006).

Measuring theory was not fully recognised as a branch of mathematics until the late 19th century when Ancient Greece Archimedes tried to calculate the area of the circle. Émile Borel, Henri Lebesgue, Johann Radon, Constantin Carathéodory, and Maurice Fréchet laid modern measure theory foundations (Bauer, H. 2001).

Our ancestors created a very original "algorithm" in calculating estimated foot length. The "algorithm" is the very first mean calculation in estimating length. The formula is relatively simple in using aggregate size divided sixteen people to estimate "1 foot". Later the formula was improved by ignoring the two shortest and longest feet.

Modern measure theory development has focused on mathematics fundamentals that can resolve topological measure space issues, which developed from two-body theory dated back to the Newton era. The interest in developing measuring theory at a new level is overgrowing.

3.1.3 Artificial intelligence algorithm is related to probability theory foundations

Artificial intelligence deep learning technology is based on probability theory which is part of mathematical theories. Machine learning can predict the probability of measurement to estimate the objective length, size, angles and colour through high accuracy training to achieve better outcomes of measurement results.

Machine learning is also like an algorithm created by the Greek ancient to use what the people know to learn what we do not know. The relationship among AI, Machine learning and deep learning presented in Fig 3.2**.**

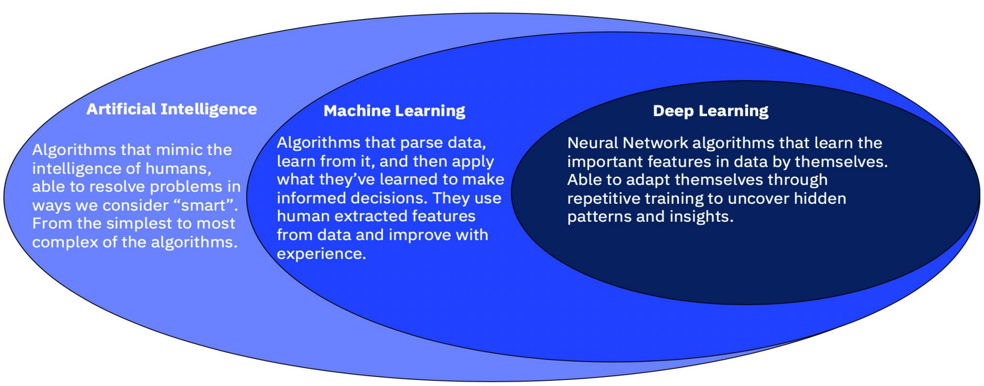

Fig 3.2 Relationships for deep learning, machine learning and artificial intelligence (Schmidhuber, J. 2015)

Turing Test, also known as Imitation Game, is fundamental research in the first giant step of machine learning and defined "Machine can think and Machine can play the game where leads to the next stage of deep learning algorithm development era- convolutional neural network (Turing, A.M. 1939). Deep learning is a class of machine learning algorithms composed of multiple processing layers to learn data representations with multiple levels of abstraction. The below diagram presents the relationship between Artificial intelligence, machine learning and deep learning (Schmidhuber, J. 2015).

John von Neumann's research in the axiomatisation of mathematics, especially in Euclid's elements, reached a new level of rigour and breath from axiom schema, which Richard Dedekind and Charles Sanders Peirce contributed in the late 19th century. Thanks to Hilbert's axioms contributions, research also reached a new level in geometry. Von Neumann's research could reach a new height on naive set theory without Russel's paradox setback until the problem of an adequate axiomatisation of set theory was resolved implicitly about twenty years later by Ernst Zermelo and Abraham Fraenkel (Jean,V,H. 1967). The research sets the foundation of the later development of DNA theory were led to artificial intelligence algorithms.

The axiom of foundation proposed that every set can be constructed from the bottom up in an ordered succession of steps through the principles of Zermelo and Fraenkel. If one set belongs to another, the first must come before the second in succession. The axiom excludes the possibility of a set belonging to itself (Jean,V,H. 1967). To demonstrate that the addition of this new axiom to the others did not produce contradictions, von Neumann introduced a method of the demonstration called the method of inner models, which became an essential instrument in set theory.

The second approach to the problem of sets belonging to themselves took as its base the notion of class and defined a set as a class that belongs to other classes, while a proper class is defined as a class that does not belong to other classes. On the Zermelo–Fraenkel approach, the axioms impede the construction of a set of all sets that do not belong to themselves (Jean,V,H. 1967). In contrast, on von Neumann's approach, the class of all sets that do not belong to themselves can be constructed, but it is a good class, not a set.

3.2 Convolutional neural network and deep learning

Artificial intelligence, including deep learning, is one of the fundamental discoveries and technology to have the application become a self-learning based system. Programmers write most software and application codes are deal with problems and applications within a fixed frame environment. Dealing with the complex problem of changing environment is where Artificial intelligence deep learning technology plays in. Machine learning opens a new era to science technology development with its powerful predictive capabilities in numerous disciplines. Many cases, such as medical imaging applications, are typical examples of machine learning playing a significant role in assisting doctors in identifying the Covid with C.T. scanners (McCollough, C.H; Leng, S. 2020). In many cases, the researchers could not find the differences between prediction and understanding in fundamental science progress. Deep learning networks are formed by significant linear regressions like human neural networks. An output image data is formed by variable input images with linear regressions—classical application in deep learning networks like identifying the portal frame structure types. The deep learning networks can also do measurement calculations based on analysing the shape of essential objectives to estimate their length or width like below Fig 3.3.

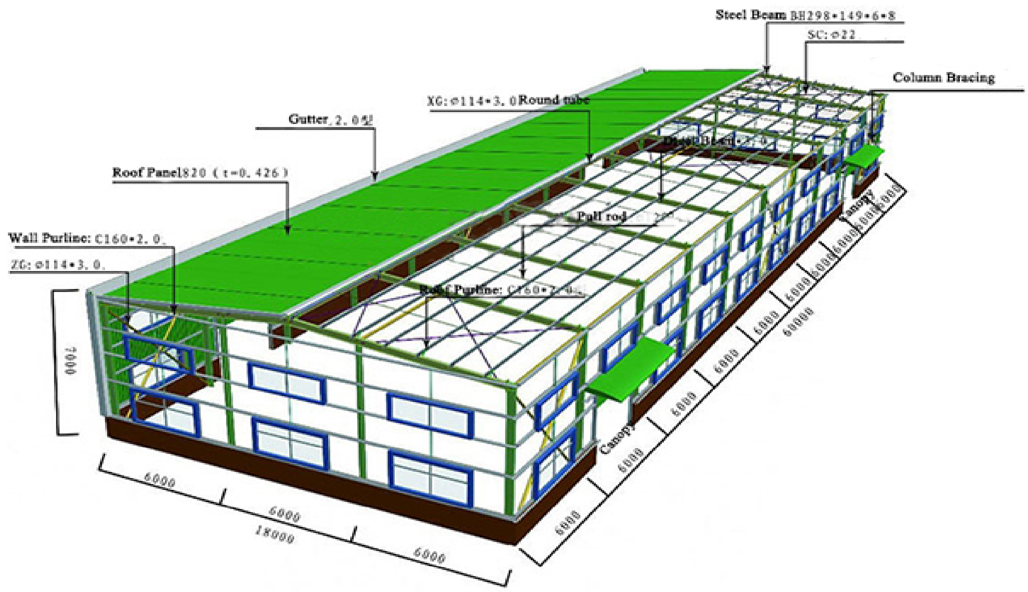

Fig 3.3 typical example of AI measurement (McCollough, C.H; Leng, S. 2020)

3.2.1 Artificial Neuron

Weights and biases commonly referred to as w and b, play critical roles in linear regression with learnable parameters in neural networks in the machine learning model. Neurons are the basic units of the neural network; in this research, each neuron in a layer is connected to relevant neurons partially or whole in the next layer like below Fig 3.4. The following formula presents the relationship between neurons, bias and weights. Weights and bias are applied to the input during neuron transmitting (Gillespie, T; Boczkowski, P; Foot, K 2014).

$$Y = \sum(weights * input) + Bias \tag{3.1}$$

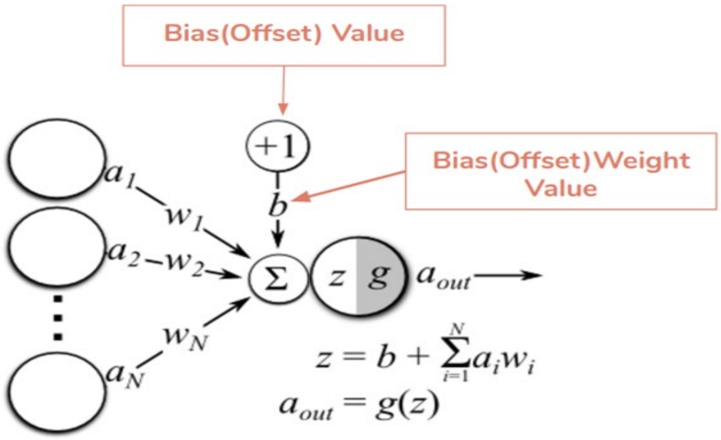

Fig 3.4 An artificial neuron (Gillespie, T; Boczkowski, P; Foot, K 2014)

Weights play an influential role in neurons transmitting and determine the strength of transmitting signals connection between two neurons. In comparison to the weights, biases are constant and additional input into the next layer with a constant value of 1. The previous layer does not influence the value of biases, but biases connect with their unit weights (Gillespie, T; Boczkowski, P; Foot, K 2014).

The bias unit guarantees that even when all the inputs are zeros, there still be activation in the neuron.

3.2.2 Linear Regression

Regression refers to methods for modelling the relationship between one or more independent variables and a dependent variable. In the natural sciences and social sciences, the purpose of regression is most often to characterise the relationship between the inputs and outputs. On the other hand, machine learning is most often concerned with prediction (Freedman, A, D. 2009).

Regression problems can be commonly seen in predicting a numerical value scenario, and it is recognised as one of the leading solutions to many predicting value issues. The common practice of regression problems is across a wide range, such as logistic forecasting inventory, accommodations prediction or retail predicting price.

The net requires a model parameter such as weights and biases in the linear regression model to set up prior to using it. Deep learning frameworks often have a predefined method to initialise the parameters in many cases.

In this research, linear regression can predict the value of measurement length and dimensions of the portal frame structure.

Essential Elements of Linear Regression

Linear regression is commonly seen as the leading solution to regression problems with its simplicity and popularity. Linear regression performs from a few simple assumptions dating back to the dawn of the nineteenth century. The regression model presented in Fig 3.5 assumes independent value X and dependable value Y is linear to define the relationship of the linear formula. For instance, the dependable value Y can be expressed as a weighted sum of the elements in X via observations. The assumption of any length is well behaved, followed by Gaussian distribution (Weisstein, Eric W. 2020).

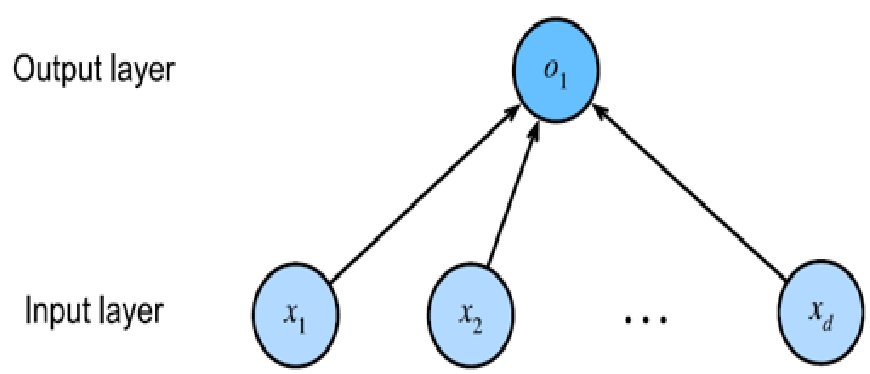

Figure 3.5 Linear regression is a single layer neural network (Weisstein, Eric W. 2020)

To motivate the approach, let us start with a running example. Suppose we wish to estimate the portal frame roofing dimension based on rafter length in meters and eaves length in meters. A model is conducted to predict the measurement of portal frame roofing structure; the installer would need to get their hands on a dataset consisting of measurements for which they know the length of rafter, steel beam height, and apex angle. In machine learning terminology, the dataset is called a training dataset or training set, and each row length of the rafter is called an example. The measurement length the installers are trying to predict is called a label or target. The independent variables length and height upon which the predictions are based are called features.

3.2.3 Forward propagation and backward propagation

Forward propagation (or forward pass) refers to the calculation and storage of intermediate variables (including outputs) for a neural network from the input to the output (Binder, J; Murphy, K; Russell, S. 1997). In comparison to forwarding propagation, backward propagation, also referred to as backpropagation, is the method of calculating the gradient of neural network parameters. In short, the method traverses the network in reverse order, from the output to the input layer, according to the chain rule from calculus. The algorithm stores any intermediate variables (partial derivatives) required while calculating the gradient for some parameters (Binder, J; Murphy, K; Russell, S. 1997).

At each neuron in a hidden or output layer, the processing happens in two steps:

1. Pre-activation is a weighted sum of inputs, i.e., the linear transformation of weights w.r.t to inputs available. Based on this aggregated sum and activation function, the neuron decides whether to pass this information further or not.
2. Activation: the calculated weighted sum of inputs is passed to the activation function. An activation function is a mathematical function that adds non-linearity to the network.

There are four commonly used and popular activation functions — sigmoid, hyperbolic tangent, ReLU and Softmax.

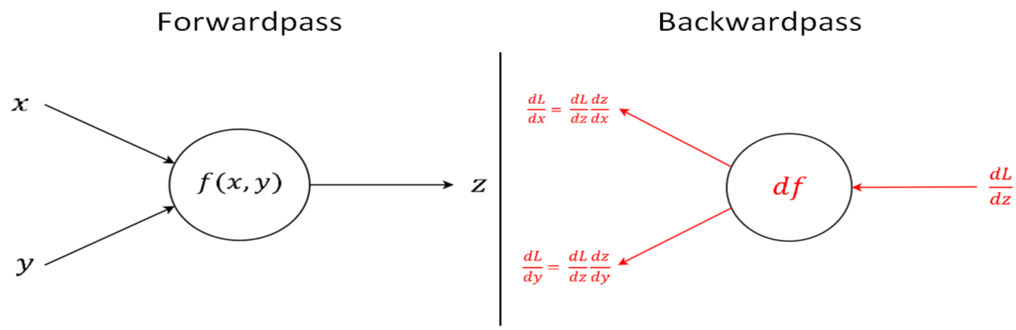

Figure 3.6 differences in Forward and backward propagation in CNN (Gillespie, T; Boczkowski, P; Foot, K 2014)

Adopting the activation function can perform the neurons calculation of weights and biases check to ensure the functions are placed in correct order to ensure the performance of forward propagation or backward propagation. The activation functions are like a balancer to calculate the sum of weights and biases and distribute them equally to activate neurons by its powerful calculation function. Most non-linearity has been added to transform input signals to outputs by differentiable operators. Activation functions are fundamental to deep learning and play a critical role in developing algorithms (Gillespie, T; Boczkowski, P; Foot, K 2014). Fig 3.6 presents the differences between forward and backward propagation in algorithm.

Softmax function, also known as softmax, is a logistic function to multidimensions based on Luce's choice axiom (Bishop, C, M. 2006). The main application of the softmax function is used as the last activation function of a neural network to normalise the output of a network to a probability distribution over predicted output classes (Goodfellow, B, A. 2016). The equation 3.2 presents the softmax function in algorithm.

$$\sigma(z)_{\mathrm{i}} = \frac{e}{\sum_{j=1}^{k} e^{z}{}_{\mathrm{i}}} \; for \; i = 1, \ldots., K \; and \; z = (z^{1}, \ldots., z_{\mathrm{k}}) \in R^{\mathrm{k}}. (3.2)$$

3.2.4 Convolutional neural network

Convolutional neural networks, also known as CNN, are revolutionised artificial neural networks in many artificial intelligence applications. The CNN has an outstanding feature characterised by a convolutional layer composed of a convolutional layer, a pooling layer, and a fully connected layer. The model constructs human brain neural networks, allowing many variance inputs to generate a specific outcome (Zhang, W. 1988). The fundamental design of CNN is based on a mathematical combination of two functions to produce a third function. In order to produce a feature, a map requires a kernel is applied to input data. The main application in using CNN is imaging processing, which allows different input images to be extracted at different levels.

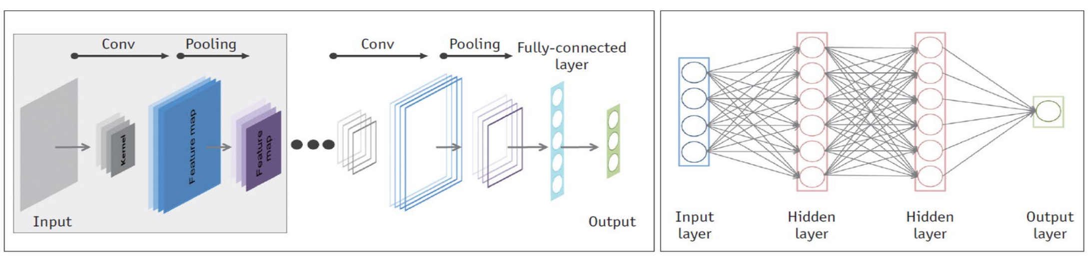

Figure 3.7 the basic functions layout of CNN (Zhang, W. 1988)

Convolutional Neural Network is the centre core of deep learning. The architectures of CNN can be hardly replaced by the next successor in commercial applications and research fields in image recognition, object detection and semantic segmentation. CNN development can be dated back to 1986 when Rumelhart, Hinton and Williams initiated Back Propagation, B.P. algorithm to identify marginal differences from the output to form the human neural network (Habibi, A, H. 2017). There are five main steps of convolutional neural network processes: convolution, ReLu Layer, max pooling, flattering and fully connection to form the CNN, which are presented in Fig

3.7. Softmax functions play a critical role in ensuring that the process achieves total value and that the layers are fully connected to yield results.

Average pooling calculations play a critical part in CNN, which defines the average value of the target area in comparison to max-pooling only extracts the maximum value in the target area. The improvement from average pooling calculations defines the fully connected layers map the features extracted by the convolutional layers and the pooling layers to the final model outputs (Scherer, D; Müller, A, C; Behnke, S. 2010). One of the critical components of CNN is an activation function that transforms the outputs of linear operations such as convolutions nonlinearly can perform complex tasks with its neural networks capability. A typical example of a nonlinear activation function is the rectified linear unit, the ReLU function (Romanuke, V. 2017). Hence, the CCN is chosen in the portal frame research deep learning model in measuring application for the following reasons.

First, CNN is efficient in training models variable numbers of parameters with connecting to the following relevant neural networks. The key facts indicate that CNN connects two neurons into a parameter to be trained between the two neurons without bias considerations. Hence, CNN can handle enormous parameters in shared networks. The training speed and length of the entire project has been significantly reduced.

Secondly, CNN does not connect all the neurons in the next layer but exclusively to a small region of neurons in the next layer through the same kernel in the convolutional layers. The activities of CNN again proved that human brain training is very similar to the artificial intelligence computation neural networks functions. The typical example in this research is portal frame imaging with input layers of 256 x 256 and output layer 256 x 256, where it is possible to produce 4, 294,967,296 parameter layers connection to be trained in fully connected neural networks. The calculus is presented in equation 3.3

$$([256 \times 256] \times [256 \times 256]) = 42,9496,72 \quad (3.3)$$

Nevertheless, CNN uses a 3 x 3 kernel to connect tiny regions in the entire neural network, which reduces the training to 9 parameters (LeCun, Y. Boser, B. 1989). Of course, the training time is significantly reduced to make the CNN self-learning in large numbers of images in a short period is possible. For example, smartphone applications can be used to make an original photo blurred or sharpened by using filters. In CNN, however, kernels are not predefined but are trained to perform a specific task from raw data. Kernels that are determined as the result of training are applied to the input images, then various feature maps at different levels are produced in the CNN. Third, CNN is more efficient for a completely new task because an already trained CNN can be slightly tuned for the new task. Finally, CNN has outperformed other algorithms on image analysis, especially in pattern and image recognition applications until now. For example, all winners of the ImageNet Large Scale Visual Recognition Challenge (ILSVRC) that used CNN based models, AlexNet, won the challenge in 2012 (Krizhevsky A, Sutskever I, Hinton GE. 2012). The below figure 3.8 presents the process of how CNN works.

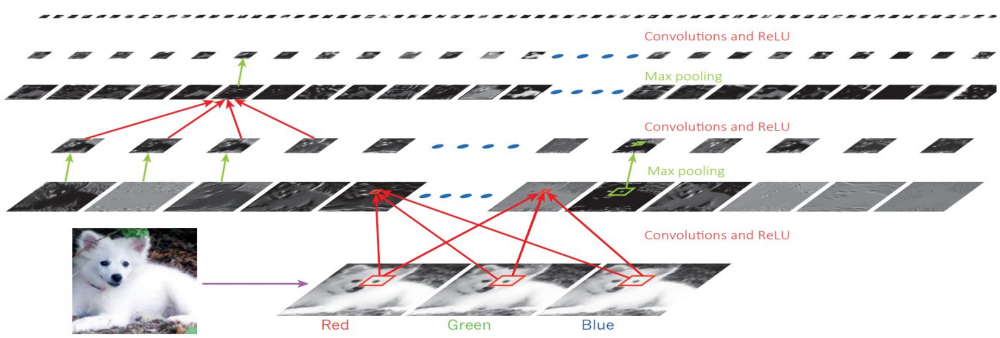

Figure3.8 the process of how CNN works (Krizhevsky A, Sutskever I, Hinton GE. 2012)

Convolution can be defined as the first layer which extracts features from an input image. Essentially, it is a matrix multiplication of the image matrix and a learnable filter matrix. The use of different filter matrices helps extract different features from the image (Szegedy, C; Liu, W; Jia, Y; 2014). The convolution process is much like the Human brain process which filtering processes allow the capture of essential and relevant data in a complex convolution net.

The following step after convolution is the pooling step, which is responsible for reducing the resolution of convoluted features, even more, leading to reduced computational requirements such as noise reduction and filtering dominant rotational and positional invariant features. The Fig 3.9 presents the relationship between pre-trained CNN and CNN complex. The pooling stage contains two processes which are max pooling and average pooling. Max pooling refers to the process of returning the maximum value from the portion of the image, which compares to average pooling returns the average of all the values from the portion of images covered by the kernel.

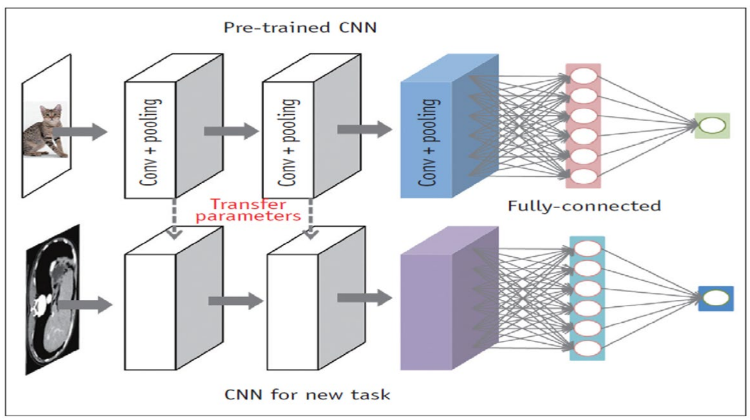

Fig 3.9 pre-trained CNN in CNN complex (Szegedy, C; Liu, W; Jia, Y; 2014)

Unlike the pooling process presented in Fig 3.10, the unspooling stage does the opposite of the pooling, which converts a single value into a patch of values—key processes including nearest neighbour, bed of nails and max unspooling processes (Géron, A. 2019).

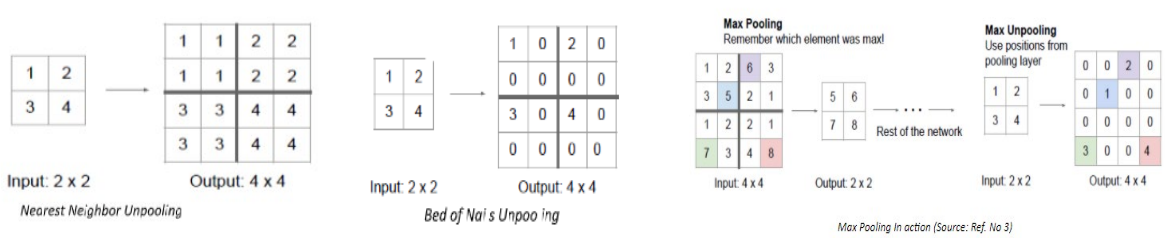

Figure3.10 three different methodologies which are under the Unpooling stage (Géron, A. 2019)

3.2.5 Deep convolutional neural network

AlexNet is a deep convolutional neural network (CNN) designed by Alex Krizhevsky, completed in the ImageNet large scale visual recognition challenge ILSVRC in 2012 (Krizhevsky A, Sutskever I, Hinton GE. 2012). AlexNet contains eight layers of CNN, and the system requires pre-trained data sets that can process more than one million images from the pre-trained database.

AlexNet is the "ancestor" level of the convolutional neural network, and its evolution of development advances the image classification on datasets from manual handwriting to automatically building the data sets. ImageNet is a classical problem solver in building robust data sets that contain up to 22,000 classes across fifteen million pixels (Krizhevsky A, Sutskever I, Hinton GE. 2012).

AlexNet was classified as a deep convolutional network, and it was built to accommodate coloured images of size (224x224x3). A classical AlexNet sample chart is presented in Fig 3.11, which defines the framework of AlexNet**.** It boasted a total of over 62 million trainable parameters. Initial research of AlexNet was trained on the ImageNet LSVRC-2010 dataset using a dataset of 128 from Alex Krizhevsky. The outcome was impressive compared to the early handwritten models in both quality and productivity.

In summary, CNN proves probability theory foundations are the artificial intelligence algorithm calculus base. Portal frame measurement application defines CNN as the leading algorithm to apply large numbers of images from raw data to final specific outcomes through specific kernels like the human brain.

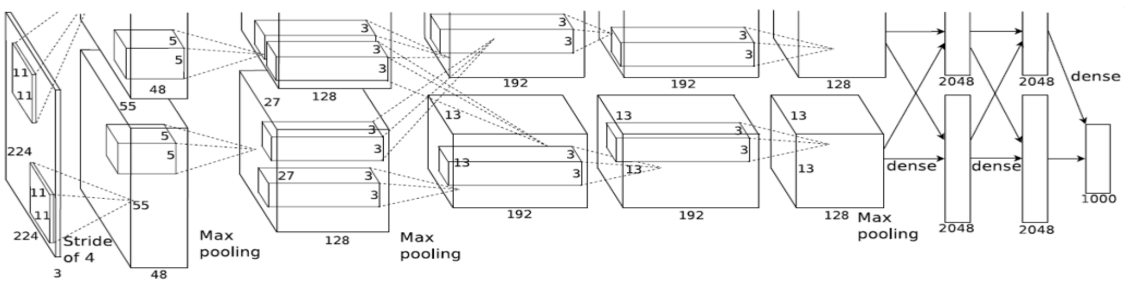

Figure 3.11 Alextnet (Krizhevsky A, Sutskever I, Hinton GE. 2012)

Similar to the above ancient "algorithm", artificial intelligence in portal frame structuring measuring conducts massive training data input from the actual environment in order to build a solid algorithm as the core "CPU" to process the labelled data to generate accurate outcomes.

3.3 Research roadmap

3.3.1 Research design

3.3.2 Traditional methodology

The current traditional methodology in measuring the roofing has been conducted through interviews with roofing specialists and site visits. Current processes from Worksafe has been summarised as follow (BPWOR, MBIE. 2012),

1. Site preparations: all personnel apart from the roofing specialist shall be escorted from the roof, removing all potential hazards that may harm the roof measurement inspector.

2. Falling off system protection such as access machine and machine operator shall be arranged prior to the operations. All roofing measurement personnel shall wear height harness protection with appropriate license or certificate of operating in height.

3. Going to the roof: appropriate measurement tools such as distance laser measuring tools tape measures shall be prepared prior to the roof measurement.

4. Calculations: the roofing measurement specialist shall do another onsite measurement based on their experiences after actuating the measurement. The main reason for this measurement calculation is due to sites installations quality inaccurate, and eaves and rafter size may vary from side to side of the portal frame structures, which could cause even more installation work.

In addition, Google Maps has also been introduced to the roofing industry. However, the accuracy of Google Maps variance can be ranged from 40% to meaningless unpredictable data if the end-users do not have pre-knowledge on conditions of Google Map services. So the methodology has not been counted as one of the sustainable solutions to this research. Forty roofers have been interviewed in this research project, and none of them agreed that using Google Maps can solve their current issues.

3.3.3 Research parameter set up

Self-supervised deep learning is selected in this measuring application. This measuring application's two key facts outcomes are expected to be a self-running system to the end-users. The self-supervised deep learning methodology is related to supervised learning, which requires extensive training data sets input, producing relatively accurate yield results that the supervised learning model could not achieve.

Following main criteria in using self-supervised in a portal frame measuring application could be assessed and determined final research parameter set up (Abshire, C. 2018) ,

Technical competence

1. No requirement of applying professional engineers or technology experts to use the system

2. Cloud base system does not require individual device hardware storage

3. Continuous training of algorithms by generating group site images into landscape photos, pictures of portal frame rafter, apex angle and eaves

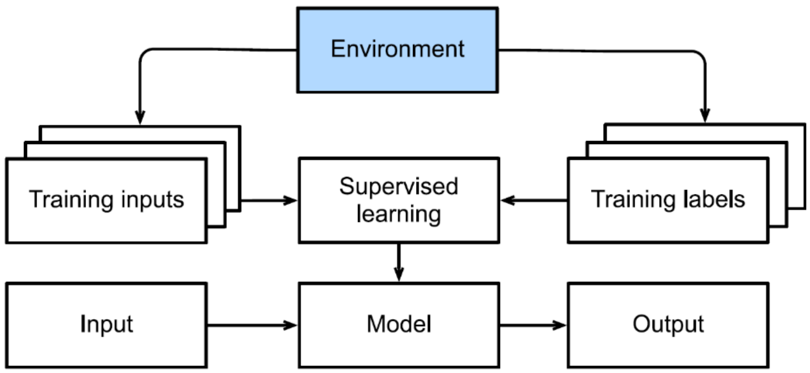

Figure 3.12 basic training functions (zhang, et al,. 2021)

The research conducts simulation in the natural environment in Fig 3.12, highlighting images from different distances and reflecting the objective's scale and pixels. The algorithm training of the image starts from a distance of 11m to 35m, covering a relatively large range of the portal frame measurement range. A steel metal ruler as the objective has been placed on the fence to test the field view of the camera lens and images pixels. Up to 35m distance in Fig 3.13, the camera lens presents the unit of the ruler very clear and is possible to use in measuring the portal frame rafter length.

Fig 3.13 pre-trained images

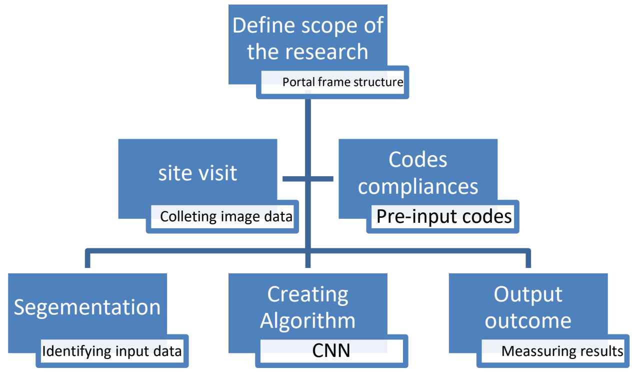

Figure 3.14 research training design

Artificial intelligence deep learning is able to identify different types of the portal frame, which depends on the training algorithm. The research training parameter set up presented in Fig 3.14 The three standard portal frames structure has been selected at the initial stages: pitched roof, tapered roof, and propped roof portal frame. Camera optical zoom range calculations take into account the measurement of objective pixels and sizes of height and width. Initial image collection devices' initial requirements are critical to determining the algorithm training quality. Hence, this research selects leading high-definition camera Nikon D5500 with VR 55-300mm lens to tailor for covering the range between 10m to 80m in wide-angle, based on actual site requirement in Fig 3.15. Further recommendation and improvements on devices requirements could be significantly reduced due to the algorithm continuing in training itself to improve the analysing efficiency and accuracy with reduced pixels of collected images. There is a possibility that using a high-resolution pixels camera from an intelligent cellular phone can achieve high-quality outcome results.

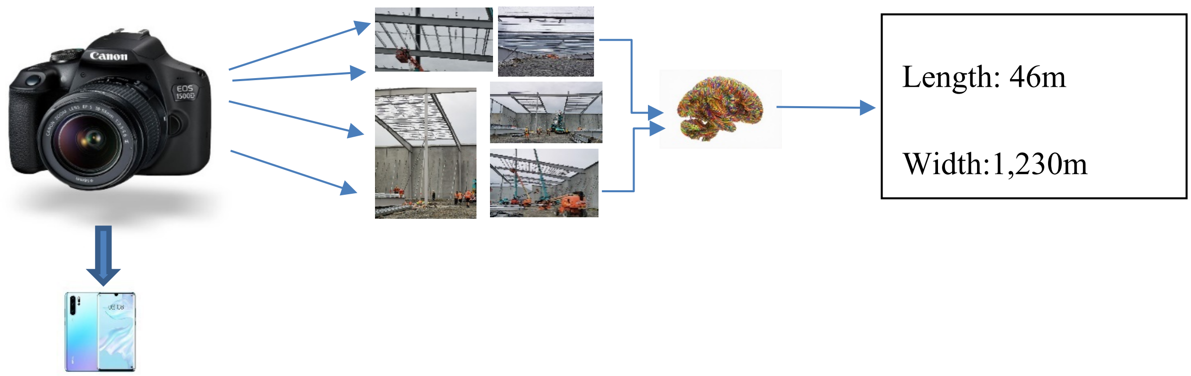

Figure 3.15 how the concept of portal frame measuring system works

Measure scale and distance and pixels determine the camera's capability to cover what types of portal frames. Identifying the distinguishing features of Portal frame roofing structures such as steel beam span length across common types of the portal frame, Roof pitch angle 3° to 5° in pitched roof portal frame structure, cellular beams in tapered section propped portal frame in propped portal frame. Prominent features from different individual portal frame structures can assure objection detection accuracy and quality, making deep learning training relatively more effortless than using other standard features such as concrete panel or steel beam height to classify the types of portal frame structures in Fig 3.16.

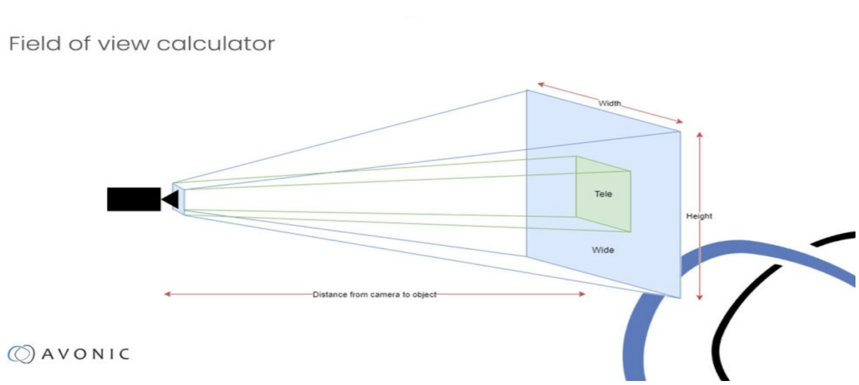

Figure 3.16 principles of camera lenses work between distance and pixels (Avonic, 2021)

After determining the portal frame category, the deep algorithm initiates critical elements such as rafter span size and roof pitch angle measuring via the site or offsite images collection. The rest key elements could be based on codes requirements to be automatically analysed and calculated via cloud base to finalise the estimated results.

3.4 Deep-learning based image segmentation for portal frame measurement

There are also two crucial tasks in computer vision that are similar to classification: image segmentation and instance segmentation. Following methodologies in distinguishing objectives from semantic segmentation can explain how the segmentation works in artificial intelligence (Linda G. Shapiro and George C. Stockman. 2001).

Image segmentation methodology can simply use the correlation between pixels by dividing an image into several constituent regions without label information required during the algorithm training. However, the downsides of using the methodology cannot guarantee the quality of segmented regions with obtaining semantics during prediction (Linda G. Shapiro and George C. Stockman. 2001).

3.4.1 Semantic segmentation versus instance segmentation

Semantic segmentation can recognise pixels level from the input image by dividing the image into different regions which belong to different semantic classes. The dataset process plays a critical role in processing images into different regions by dividing different pixels levels. In semantic segmentation, since the input image and label correspond one-to-one to the pixel, the input image is randomly cropped to a fixed shape rather than rescaled (Girshick, R., Donahue, J., Darrell, T., & Malik, J. 2014).

In semantic segmentation, the methodology requires rescaling the predicted pixel classes back to the original input image's original shape. Such rescaling may be inaccurate, especially for segmented regions with different classes (Dumoulin, V., & Visin, F. 2016). In order to resolve the inaccuracy issue of the images, cropping the same area of image with fixed shape in labelled random input images. Below Fig 3.17 is an example of the specific semantic image training in aircraft images. In order to identify front aircraft one and background aircraft, the images have been cropped with shapes for future algorithm training purposes.

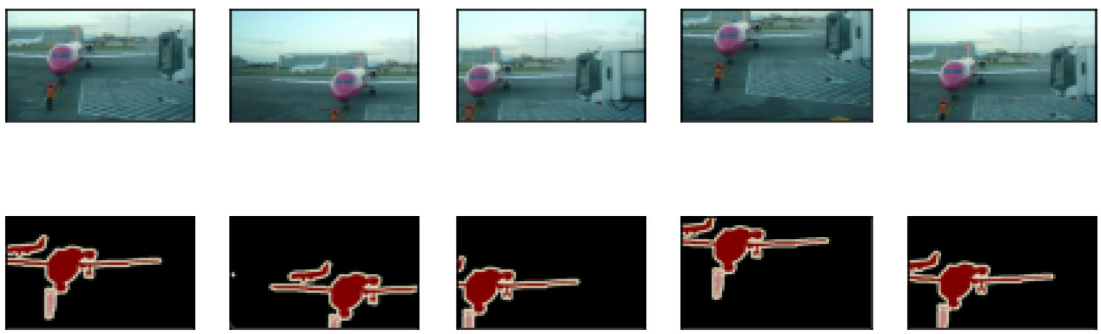

Fig 3.17 Semantic segmentation for aircraft (Zhang et al,. 2021)

Instance segmentation is also called simultaneous detection and segmentation—the instance segmentation studies how to recognise the pixel-level regions of each object instance in an image (Girshick, R., Donahue, J., Darrell, T., & Malik, J. 2014). Unlike semantic segmentation, instance segmentation needs to distinguish semantics and different object instances. For example

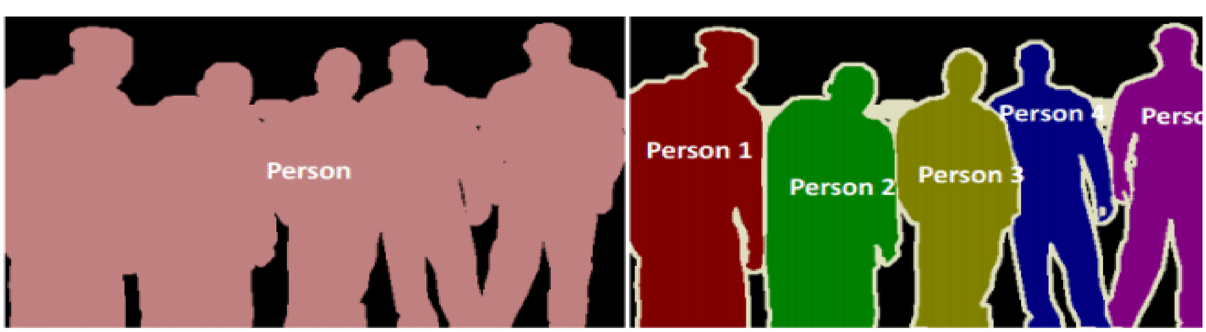

Fig 3.18 semantic segmentation (a) versus instant segmentation(b) (Google, 2021)

in Fig 3.18, if there are two groups of people in the image, for instance, segmentation needs to distinguish which of the group people a pixel belongs to which group.

In this research thesis, portal frame structures can be segmented into essential and not essential structures where can be calculated into the areas of the roofing structure. Geometric image shapes training in Fig 3.19 is crucial in this research parameters set up. Rafters and eaves become essential parts for the training algorithm to identify the portal frame key components for further calculations. Labelling fixed distance and fixed length of objective images can improve the future deep learning model accuracy.

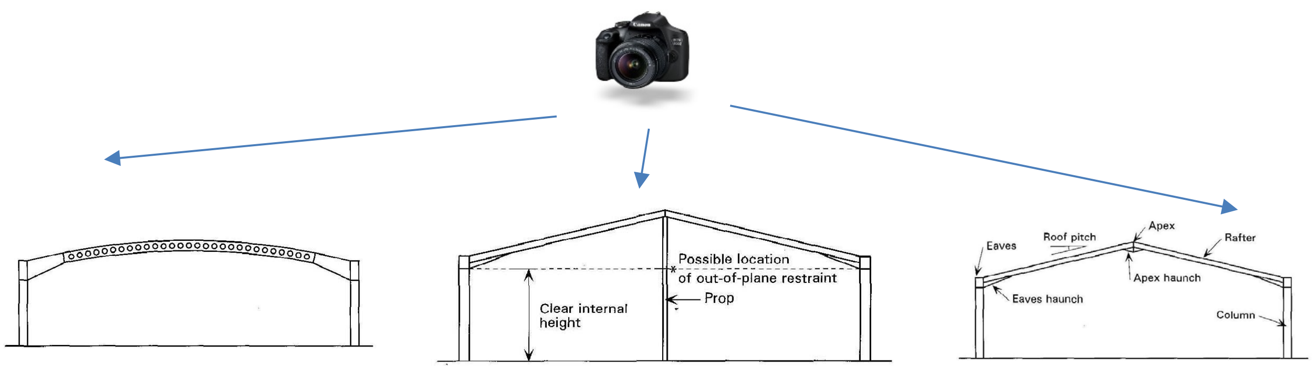

Fig 3.19 the research system works in identifying different types of portal frame structures

The same methodology can apply to identify the portal frame structures. Below are images that identify the rafter by utilising the semantic segmentation methodology.

The same methodology in using a training algorithm with a fixed length ruler can measure the rafter length.

Segmentation creates the first layer in Fig 3.20, and critical kernels in connecting various images in further training steps are ready for artificial intelligence algorithm training.

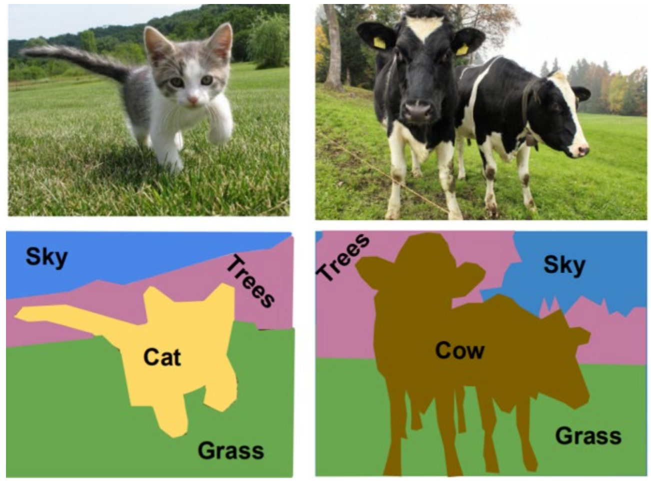

Figure 3.20 segmentation in an imaging application (Chong F, 2020)

3.4.2 Algorithm Training in measuring portal frame application

The Greek ancestors created a very original "algorithm" in calculating estimated foot length. The "algorithm" is the very first mean calculation in estimating length. The formula is relatively simple in using aggregate size divided 16 people to estimate "1 foot". Later the formula was improved by ignoring the two shortest and longest feet. In this research, we could apply a similar ancestor "algorithm" in using fixed length as a standardised measurement meter to apply to variable-length measurement. Below Fig 3.21 presents how the algorithm applies to portal frame measuring research project.

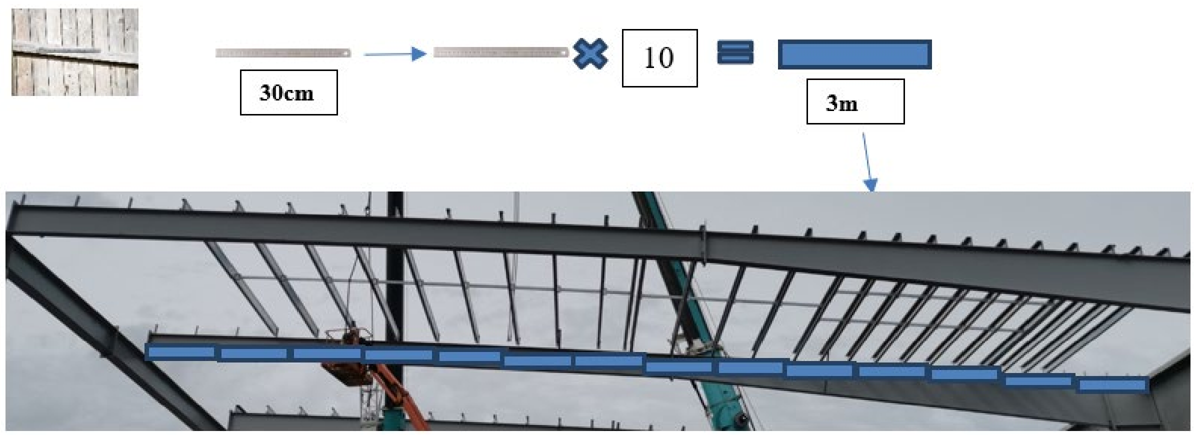

Figure 3.21 how research concept functions in practice

Furthermore, it is emphasised the critical role played by nonlinear dynamical systems for the process of understanding. The path of the future of science could be marked by a constructive dialogue between big data and big theory, without which we cannot understand.

Appropriate deep learning technology can be selected to measure portal frame roofing structure based on the following conditions.

- The AI deep learning measuring system shall achieve an accuracy of less than 20mm tolerance.
- The AI deep learning measuring system shall comply with the current New Zealand building codes practice.
- The AI deep learning system shall be easy to use for the end-users.

3.4.3 Supervise learning versus unsupervised learning

Consumers are browsing millions of products every day, and the suppliers or retailers are eager to understand users' browsing activities in deep analysis to group the shopping behaviours.

This problem is typically known as clustering. The study case of retail shop behaviour can be simply using unsupervised training methods to learn shopping behaviour from the consumers.

As a form of unsupervised learning, self-supervised learning leverages unlabelled data to provide supervision in training, such as by predicting some withheld part of the data using other parts. For text, training models to "fill in the blanks" by predicting randomly masked words using their surrounding words in big corpora without any labelling effort (Devlin et al., 2018). For images, we may train models to tell the relative position between two cropped regions of the same image (Doersch et al., 2015). In these two examples of self-supervised learning, training models to predict possible words and relative positions are both classification tasks from supervised learning.

In comparison to unsupervised learning, a supervised learning algorithms system is trained with examples and outcomes from historical value data sets to predict and generate new data sets based on past examples. In this research, to measure the rafter and eaves can introduce supervised learning algorithms to tailor for the application to generate new data set outcomes based on training samples.

3.5 Modelling built up in Smales Road case study

The model algorithm is based on essential components to identify the steel rafter from image data sets input like the picture below with fixed training distance to measure the size. 10m distance has been marked for this project at all times to take training photos in Fig 3.22.

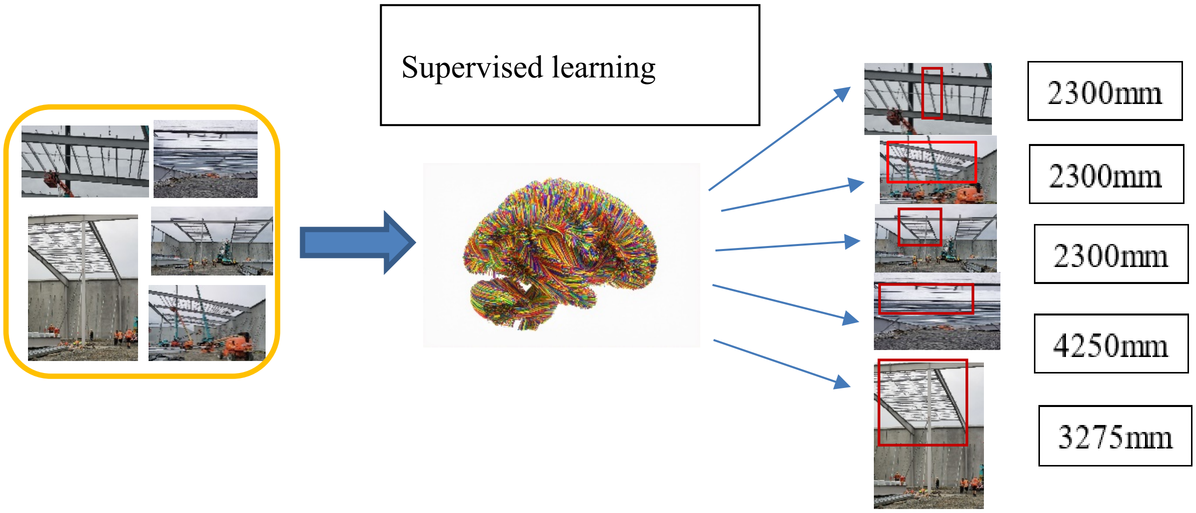

Figure 3.22 supervised learning applies to the research

3.5.1 Collecting training image data

3.5.1.1 Site visit

The Smales road site visit has been arranged to collect authentic portal frame structure construction images to build a training algorithm. The actual site environment can improve the accuracy and reality environment to train model innovative, which compares to lab training with a consistent environment.

Engineering fabricators, also known as engineering shops, consistently collect portal frame structure images prior to being delivered to the site. There is a hint that the process of measurements could be completed in the shop in the future.

3.5.1.2 Image annotation

A collective of the images was from actual Jobsite visits to be used in this research project in order to create an accurate training algorithm for future-ready.

Logistically, the methodology shall follow the consistent activities or objectives are invariance. The reinforcing bar's size is smaller than the portal frame steel beam. Multi-layer perceptron, known as MLP, is deeply connected to the case of identifying the objectives in multiple images data sets.

$$[\mathbf{H}]_{i;j} = [\mathbf{U}]_{i;j} + \sum_k \sum_l [\mathrm{W}]_{i;j;k;l}[\mathbf{X}]_{k;l}$$

$$= [\mathbf{U}]_{i;j} + \sum_a \sum_b [\mathrm{V}]_{i;j;a;b}[\mathbf{X}]_{i+a;j+b}: \quad (3.4)$$

Ideally, the system should exploit CNN knowledge. Pigs usually do not fly, and planes usually do not swim. Nonetheless, in order to identify the relevant objectives in the portal frame structure, CNN training is critical and dependable for future deep learning data sets. Below images are collected from the actual job site visits with various objectives. To identify the rafter, CNN shall specific training target with rafter images as presented in Fig 3.23.a, 3.23 b, 3.23.c and 3.23.d. Indeed, eliminating the irrelevant image data which presents in Fig 3.23 also become critical to allow CNN to learn the differences via geometry images. CNN's systematise this idea of spatial invariance, exploiting it to learn valuable representations with fewer parameters.

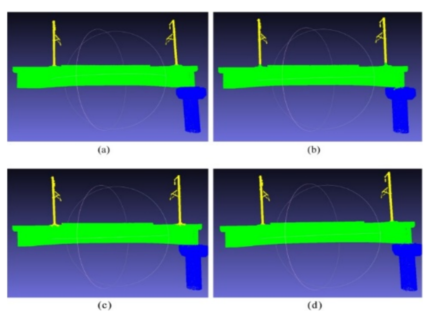

Fig 3.23 Training Rafter images with minor angle twists (Zhang et al,. 2020)

A few collective pictures of common job sites objectives such as rebar, lifting cranes, concrete beam and steel beams have been collected for this research. Objective training becomes critical for this research as the system needs to identify the key components to measure and disregard the irrelevant objectives.

Figure 3.24 common objectives at the construction site

3.6 Fully Convolutional Network (Semantic Segmentation)

A full convolution network (FCN) is a neural network that only performs convolution operations subsampling or upsampling. Equivalently, an FCN is a CNN without fully connected layers. A fully convolutional network, also known as FCN, uses a convolutional neural network to transform image pixels to pixel classes (Long et al., 2015). FCN in Fig 3.25 transform the images data like width and height of immediate feature maps back to input data via transposed convolutional layer, which is different from CNN in processing image classification and objective detection applications. Consequently, the image process can correspond as one to one at pixel-level. An output image channel dimension reflected the input image pixel at the same spatial position.

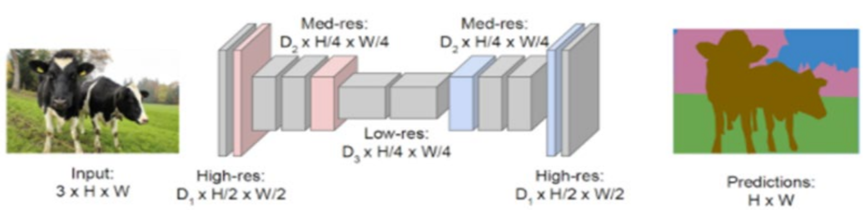

Fig 3.25 FCN sample (zhang et al,. 2021)

In comparison to CNN performance, FCN performance is highly similar to CNN networks in detecting the annotated localisations. A fully Convolutional Network is a popular solution to the architecture by using its Downsampling and Upsampling.

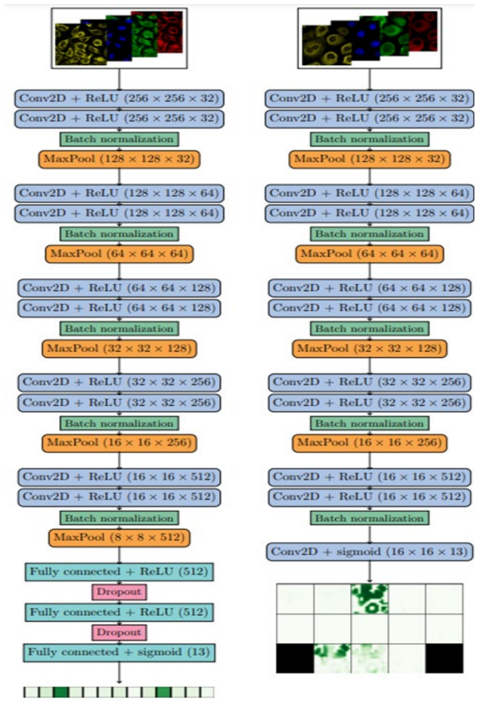

Fig 3.26 convolutional neural network CNN on the left and fully convolutional network (FCN) right architectures (Olaf, R. 2015)

From the above-presented image sample in Fig 3.26, the resolution of H x W from the initial input image is convoluted to H2 x W2, and finally, the image resolution is convoluted to H/4 x W/4. The analytical process obtains mini heatmaps of the different objectives such as cows, grass, trees and sky with an intensity equivalent to the probability of occurrence. At the next stage, heatmaps are upsampled and finally aggregated to a high-resolution segmentation map where each pixel is classified into the highest probability class. Some key concepts need to be defined prior to the next stage.

Unit is a leading solution to FCN in practical research and building architecture. The process replaces the pooling operations by upsampling operators where the convolutional layer has improved the resolution of the output images to learn to assemble precise output based on this information (Olaf, R. 2015).

U-net can utilise its U shape architecture network to propagate context information to higher resolution layers in upsampling part (Olaf, R. 2015). U-net network can focus on performing the valid part of each convolution without any fully connected layers. The below-presented image explains how U-net networks work. The Unet framework is structured with two 3x3 convolutions followed by a rectified linear unit called ReLu. The downsampling process includes a 2x2 max pooling operation with stride 2, which is presented in Fig 3.27. The network of Unet has 23 convolutional layers, and each layer consists of several featured channels that can be doubled at the end-users needs via the downsampling process (Olaf, R. 2015). In comparison to upsampling process, a 2x2 convolution is generated at each layer in the expansive path that correspondingly cropped feature map is necessary to cover the loss of border pixels in each convolution.

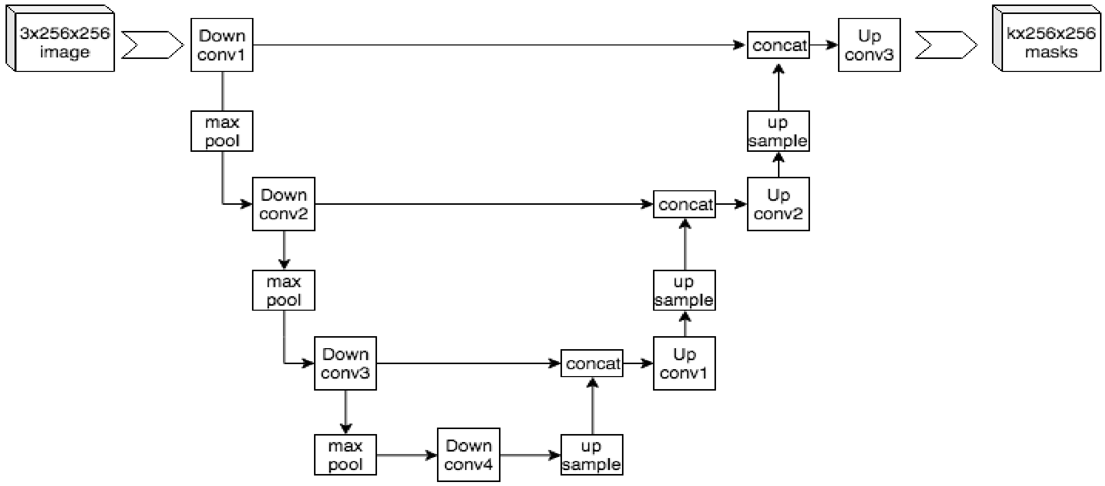

Figure 3.27 Unet system (Olaf, R. 2015)

In this research, Portal frame semantic segmentations select eaves and rafter as critical components to finalise calculation on roofing-related areas and gutters options.

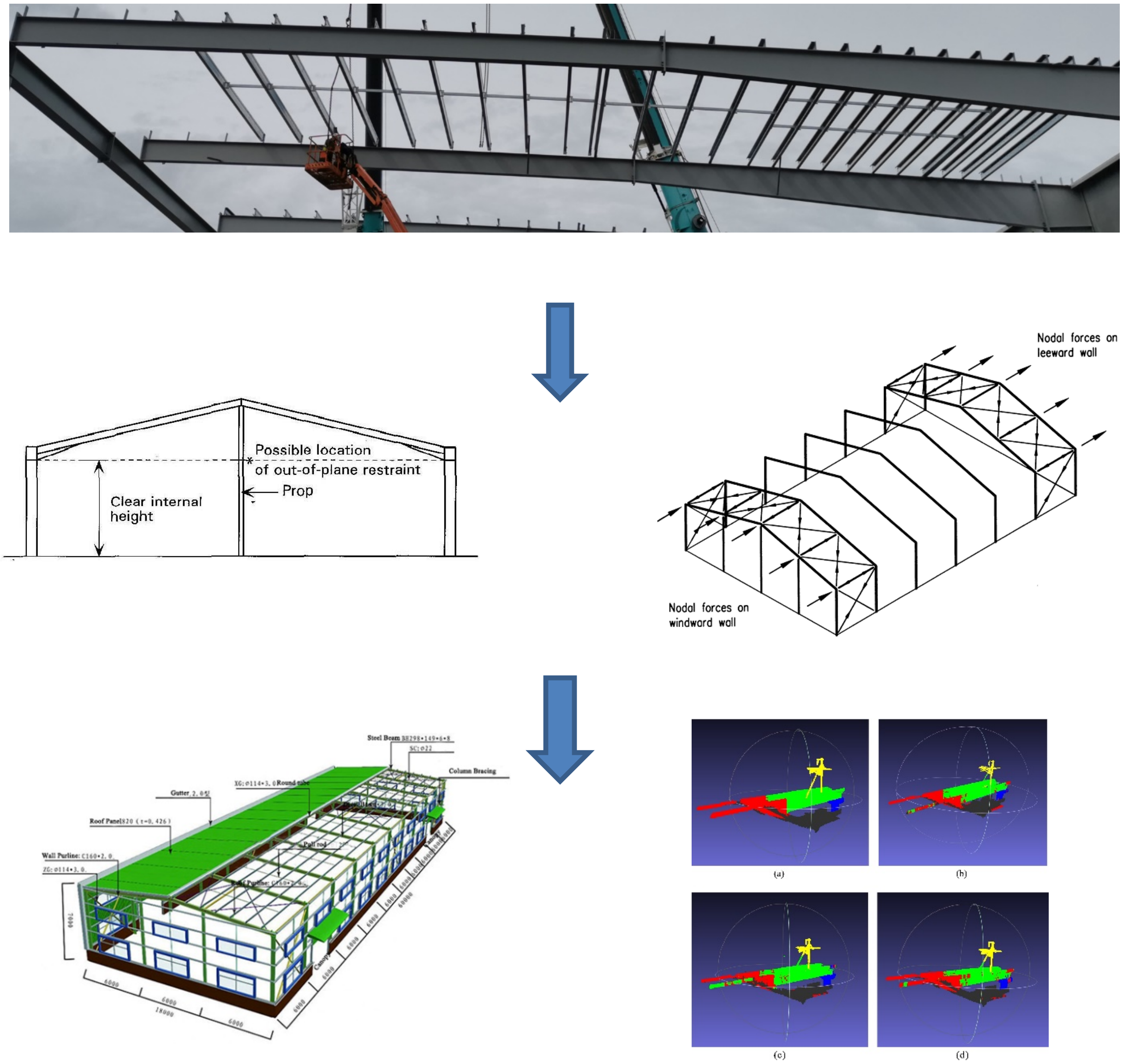

Figure 3.28 research system in a practical site measuring

Semantic segmentation plays a crucial role in initial processes in generating essential data to calculate the roofing areas in the portal frame structure. By utilising the fully convolutional network, the research can generate rafter and eaves key components measurement in order to feed the essential data to the final calculation of the roofing area in Fig 3.28. The advantages of using FCN and U-net in this research project could advance the productivity in analysing the valid data. The U-net network performs the valid part of each convolution without any fully connected layers.

3.7 Measuring training

A Canon camera is selected in use in this research to collect training data images in order to train an algorithm to estimate the size of the objectives. The research conducts simulation in the natural environment, highlighting images from different distances and reflecting the objective's scale and pixels in Fig 3.30. The algorithm training of the image starts from 11m to 35m, covering a relatively large range of the portal frame measurement range. A steel metal ruler as the objective has been placed on the fence to test the field view of the camera lens and images pixels. In order to identify the objective size, the priority is fixing the distance to narrow down from eight variable distances to one fixed distance which is 11m in Fig 3.29. The distance of 11m has been identified based on the following factors: safety distance for personnel to access the job site and camera capability to generate good quality pixels images for algorithm training.

Figure 3.29 pre-training images in measuring unit

Basic modelling built deep learning requires sophisticated work on the specific programming language. The most appropriate language for working with images is tensors, which arrive as n-dimensional arrays with three axes corresponding to the height, width, and channel axis for stacking the colour channels (red, green, and blue). For now, the research project can skip over higher-order tensors and focus on the basics.

CNN is unique in addressing low-level perpetual data to resolve many everyday operations issues, such as analysing analogue data in audio and pixels. The portal frame structure measuring is a typical example of using raw pixels data from images to generate sequences for the algorithm to study. The learning capability from deep learning algorithms could not be succeeded by traditional tools such as 3D laser scanners or tape measuring hand tools. The training processes of the algorithm is based on end-to-end training, which is very specific on details on measuring components without final adjustment jointly. However, the traditional tools are based on individual tuned structure components, which are required final system integration jointly inspected and adjustments. Typical building machine learning examples of mapping images into vectors such as the Canny edge detector (Canny, J. 1987) and Lowe's SIFT feature extractor (Lowe, D, G. 2004) is nearly impossible to replace any traditional measurement tools. The crucial parts of applying the raw data pixels to machine learning are manual engineered processes requiring sizeable skilled labour to generate a simple algorithm. In bygone days, generating the algorithm was very labour and time-intense. Even worse, the cost is not affordable to the end-users. In modern days, the manual engineered processes have been replaced by the pre model machine-learning algorithm to process raw data, and the productivity is close to "light speed" in terms of speed and accuracy compared to manual processes.

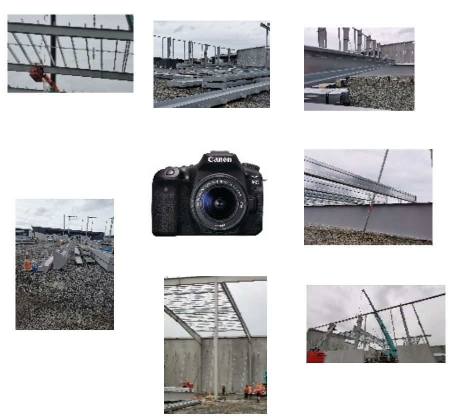

Figure 3.30 camera collects images from sites

Thus, one key advantage of deep learning is that it replaces the shallow models at the end of traditional learning pipelines and the labour-intensive process of feature engineering. In addition, the traditional domain-specific pre-processing has been replaced by deep learning with its learning capabilities. The boundaries elimination of separated computer vision can advance applications such as speech recognition structuring dimensions measuring with unity tools to resolve diverse issues.

Modern issues require modern solutions. In order to create a formal mathematics system of learning, machines require proper measures to determine the appropriate models are. The objective functions are identified as optimisation. The objective functions in machine learning are different from traditional methods, which is developer aims the lower, the better principles. The algorithm's objective functions are qualitatively identical to the newly created function in a traditional learning machine but process the low-level perpetual data to achieve the end-user goal. The disappeared objective function in the algorithm is called the loss function.

The squared error appears as the most common loss function in predicting numerical values application. The common goal of machine learning is to minimise the error rate in the loss function, especially in calculating the square of the difference between the prediction and the ground truth (Lehmann, E. L.; Casella, G. 1998). In the portal frame measuring case, the loss function plays a critical role in minimising the error rates in the loss function in the pre-trained algorithm to optimise the outstanding outcome of measurement results. Other rates beyond the error rates are challenging to optimise directly, owing to non-differentiability or other complications.

Typically, the loss function is defined for the model's parameters and depends upon the dataset (Raschka, S. 2019). In order to create the best values of the algorithm model's parameters to have the "future proof" machine learning algorithm with advanced learning capability, training data quality is essential to support the system in future performance. However, the decent quality of training data does not assure unforeseen data sets via training processes. Therefore, splitting the training data sets can reduce the error rates in building algorithms. The datasets can be split into two groups training datasets for model training purposes and test data sets for evaluation purposes. The test dataset generates the report feedback on how training datasets perform in the algorithm. The overfitting performance is a typical example of well-performed training datasets that failed to generate decent models. Boston robotics training usually collects more than 30 different training datasets to create the algorithm and guide the robotics to perform actions like walking, running and jumping. However, only one or two datasets out of thirty sets can barely achieve the performance. Hence, programmers are encouraged to select two performed datasets to merge to train the next stage and repeat the processes repeatedly. Surprisingly, the robotic can start performing martial arts after a few months of training. The processes are called iterative algorithms (Dominici, M.; Cortesao, R. 2014).

Tensors

Just as vectors generalise scalars and matrices generalise vectors, we can build data structures with even more axes. Tensors referred to as algebraic objects, which give us a generic way of describing n-dimensional arrays with an arbitrary number of axes (Google, 2015). For instance, Vectors are first-order tensors, and matrices are second-order tensors. Tensors are denoted with capital letters of an extraordinary font face (e.g., X, Y, and Z), and their indexing mechanism (e.g., xijk and [X]1;2i-1;3) is similar to matrices.

Tensors could become more critical when the research starts working with images, which arrive as n-dimensional arrays with three axes corresponding to the height, width, and channel axis for stacking the colour channels (red, green, and blue). For now, the images are over higher-order tensors and focus on the basics.

3.8 AI hardware integration possibility

Tensorflow as a deep learning algorithm coding language requires high specification graphic processing units, also known as GPUs. In general, common mistakes such as most deep learning programmers use GPUs as leading hardware to process the images data because they perceive that using GPUs is fast and efficient. However, using GPUs in transferring variable images between devices can slow down entire processes of deep learning algorithms. Delaying in processing images is caused by waiting for variable images data to be received or the image data are on the way to the following copying devices. Research indicates that several operations are much better than many single operations interspersed in coding practice (TensorFlow, 2019).

Hence, there are three modern solutions from current GPU suppliers to resolve large GPU capacity requirements.

First of all, Nvidia provides the Jetson solution on the GPU aspect. Jetson series provides a cutting edge technology solution in utilising the GPU capacity with low energy consumption. The Jetson series can perform up to twice performance as previous generations, which presents the AI developer with high-performance hardware benefits with low energy consumption.

On the other hand, Intel provides a processor solution called Movidius Myriad X VPU, which is as tiny as a USB flash drive. The Intel Movidius Myriad X VPU is programmable with the Intel® Distribution of the OpenVINO toolkit for porting neural network to the edge and via the Myriad Development Kit as MDK, which includes all necessary development tools, frameworks and APIs to implement the custom vision, imaging and deep neural network workloads on the chip (Weckler, A. 2016). The specification of Movidius is very impressive as it has 16 high-performance SHAVE cores, NCS 2comaptible with Ubuntu16.04.3 and Windows 10 operating system and support TensorFlow, Pytorch development structure (Intel, 2021).

Lastly, Xilinx presents a solution that is also compatible with standard operating systems such as Windows 10 also supports Pytorch and TensorFlow programming language. In addition, Xilinx provides a powerful open-source quantiser that supports pruned and unpruned model quantisation, calibration and fine-tuning.

3.9 Imaging data set processing

One widely used dataset for image classification is the MNIST dataset (LeCun et al., 1998).

MNIST has been considered one of the benchmark imaging data set processing models, outperforming other models in classification accuracy. Nowadays, the benchmark model of MNIST is hardly treated as a benchmark, but just sanity check for data set due to more detailed model processing images is already outperformed the MNIST inaccuracy is over 95% (Xiao et al., 2017).

The RPN is also known as the region proposal network head, and the ROI is also known as the region of interest head in two-stage methods. Both methodologies use the image features extracted by the backbone network for prediction tasks, where the rpn head is responsible for distinguishing the foreground and background and predicting the regression coefficient of the anchor box (Heng, F.; Ling, H. 2018). In contrast, roi head is responsible for predicting the specific category of ROI and obtaining the offset value used to fine-tune the bounding box. Therefore, roi enhances the global feature perception capabilities in these two stages.

In this research, we intend to use steel columns as a primary example to discuss the possibility of AI deep learning technology can resolve the current issues through creating algorithms and training image data sets to achieve the objective target. The research methodology introduced to this application can be two significant objectives. The research creates an algorithm to recognise objectives- steel column classification. The algorithms are able to estimate the length of the portal frame structures for roofing installation ready.

Image augmentation is the solution to random changes on inputting images data that generates similar but distinct training samples by expanding the size of the training set. Human face recognition is a typical image augmentation in some applications that identify the right target even with long or short hair and with beards or no beards. Thanks to the algorithm of image augmentation, training datasets are similar, not identical, which provides decent image datasets for the algorithm to learn the differences from each training dataset in Fig 3.31 with minor tweaks. Another example of image augmentation is that taking portal frames rafters on both cloudy and sunny days can reduce the model's sensitivity to colour. The success of AlexNet was not a surprise that proves that image augmentation was indispensable in playing its crucial role in the model (Bloice et al., 2017).

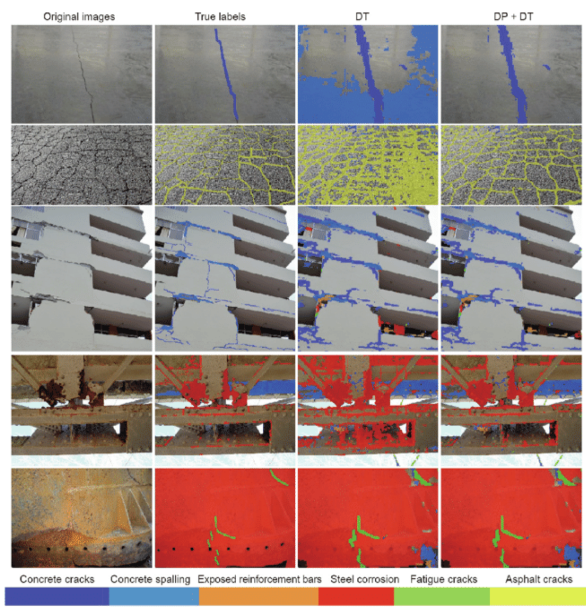

Figure 3.31 Concrete cracks identification in deep learning (Bloice et al., 2017)

Current technology for measuring significant objectives

Measuring significant objectives is a prevalent and familiar topic in the construction industry. Many available technologies have been adapted to the current industry, and the accuracy of results are varied due to external environmental effects and internal hardware limitations. This research conducts a complete list of currently available technology comparisons to artificial intelligence, not the technology layer but the economic layer.

Accountable essential measuring requirements are defined as accurate and traceable for an efficient supply chain, especially for the manufacturing industry.

This research defines the following standard leading measurement technology to analyse a feasible solution in resolving the site measurement issues—many issues, as the previous chapter mentioned before, health and safety, inaccurate and inconsistent measuring results. Lastly but not least, weather restrictions.

3.10 Chaos theory in artificial intelligence image a security

With the rapid development of the Internet and network bandwidth, many digital images are transmitted across the Internet. However, sensitive and confidential images are in danger of being stolen and abused simultaneously. The standard method to protect images is to encrypt them before transmission. In recent years, chaos-based encryption has attracted much attention from academics. The reason is that chaotic systems have some intrinsic properties, such as extreme sensitivity to initial value and condition, unpredictability, and complex dynamic behaviour, which are all consistent with the essential characteristics of a good cryptosystem.

In recent years, many excellent chaos-based encryption algorithms designed to protect a single image have been proposed (Wang et al., 2020). Nevertheless, the algorithm designers face a situation where the resolution and volume of images are getting too large to handle. Therefore, the priority topic of improving efficiency on completing the encryption tasks are critical in this case. The parallel computing solution to resolve the efficiency issues in processing the data in the encryption algorithms scenarios are proposed, which the parallel algorithms can be classified into CPU based encryption algorithms (Luo, Y; Zhou, R. 2018). Practically, the CPU-based encryption algorithm is more efficient and economical to be implemented compared to the GPU-based. This summarisation is due to the nature of GPU hardware configuration requirements being the more complicated and higher cost to CPU-based in processing the data encryption and decryption. Moreover, GPU-based algorithm requires specific software to support induvial GPU hardware manufacture, which could potentially increase the cost of end-users on the operational aspect. The GPU is not popular in applying to the eld of cryptography applications due to the uncertainty that using OpenCL could not guarantee the generality of the encryption algorithm (Wang, et.al 2020). However, the CPU is universal to apply to all different hardware configurations, which minimises the cost and numbers of software to support the end-users to design encryption algorithms without the uncertainty of hardware.

The aforementioned parallel encryption algorithms are trendy in the algorithms designers community to encrypt a single image. In general, image protection does not apply to one but to multiple images with encryptions. Many new efficient algorithms solutions have been proposed to improve the efficiency of encryption of a group image (Song, et.al 2020). Many batch image encryption solutions such as Vector Quantization and other index compression processes are combined with applying to the scenario (Hu, et.al 2017). However, the limitation of the paper is only focused on compression rate and computational efficiency; security analysis of cipher-images is insufficient. Nevertheless, compared to Vector Quantization, the DNA encoding and PWLCM system can encrypt the batch images in a short period, exposing risks to the end-users with the chosen-plaintext attack (Wang, et.al 2013).

Coincidentally, the computational system's encryption algorithm for batch images also suffers security risks. The stacked autoencoder network system resolved the security issue with limitations in using a standardised size of explicit images (Song, et.al 2020). A multi-image encryption algorithm was proposed by using a two-dimensional linear canonical transformation system, in which the system only process four images at each time (Hu, et.al 2017). Hence, the efficiency issue surfaces again on encrypting the batch images. There is an unresolved common issue: each image usually requires several encryption rounds to achieve a satisfactory level of security, and the multiple rounds of keystream generation is a time-consuming process (Huang, et.al 2020).

3.11 Blue tooth, Ultrasonic, Lidar, Frequency scanning interferometry (FSI) and AI deep learning

The Blue tooth, Ultrasonic, Lidar and Frequency scanning interferometry FSI are sensor-based technology which means the individual system requires a sensor or groups of sensors to complete the signal transmission, which produces the measurement outcomes to the end-users. Compared to sensor-based technology, deep learning does not require any sensors to complete the measurement process. However, sensor-based technology takes less time in programming software than artificial intelligence. Deep learning technology requires a lengthy time to create an algorithm to perform accurate measurement tasks.

In reality, any objective measurement has accuracy issues, more or less in order to achieve high objective accuracy, parameters and more concerned with parameters set up that lead to highly accurate predictions. Fortunately, even on complex optimisation problems, stochastic gradient descent can often find excellent solutions, owing partly to the fact that, for deep networks, there exist many configurations of the parameters that lead to highly accurate predictions.

In this research parameter set up, measuring a 35m long-span steel beam requires min 35 sensors in FSI technology, 20 sensors in Bluetooth technology and ten sensors with Lidar technology. All sensors require pre-set up prior to performing measurements. In comparison, artificial intelligence deep learning technology requires no pre-setup during the measurement process, saving valuable time for all supply chain parties. Installing sensors can be a very challenging task as well. Two options are given for installing sensors from prefabricating engineering shops as the steel beam is on the ground, which is relatively safer for installers or installing the sensors on the job sites. However, the damages of sensors are at high risks during transportation and crane beam installing processes. Installing sensors onsite can be faced even more challenges as working in height require special PPE to fit for installer and time consuming for sensor installation. Productivity and accuracy are complicated to achieve with sensor-based technology.

3.11.1 Frequency scanning interferometry FSI

Frequency scanning interferometry (FSI) is an absolute distance measurement technique that combines a conventional interferometer, usually an optical fibre interferometer, with a tunable frequency laser rather than a stabilised fixed frequency laser (Stone, et.al. 1999). Many FSI technologies currently exist in the market to reply on phase information for high precision measurement. The FSI technology replies on frequency detection for distance to a single target per measurement in Fig 3.32. Methods that rely on frequency detection for distance estimation sacrifice precision but grant more flexibility, such as allowing lower signal-to-noise limits and the ability to measure multiple targets simultaneously.

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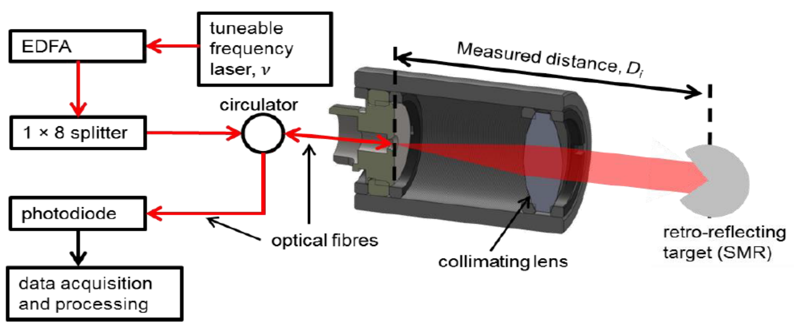

Figure 3.32 FSI working principle (Hughes, et al. 2010)

For dimensional measurement of components and assemblies up to a few metres in size, the coordinate measuring machine (CMM) is the market's most commonly used measuring tool. The most accurate CMMs can achieve expanded uncertainties of a few micrometres per metre; Leica 3D scanner in construction application uses FSI technology to measure building objectives with accuracy can achieve at 7-10 µm at 1σ under 1m distance. Large volume metrology (LVM) tools such as laser trackers, laser radar, photogrammetry, laser scanners, theodolites, total stations, and hydrostatic levels for larger-sized components, structures, or facilities are required (Hughes, et al. 2010). Measurement ranges of the LVM tools can start from one metre to hundreds of metres, which present the capability of the LVM methodology can apply to a wide range of measurement applications such as aerospace research, civil engineering and beam therapy systems (Peggs, et al. 2009).

The LVM tools can achieve an uncertainty of around a few parts in a single point in space, excluding photogrammetry. The rapid sequential measurement can apply to LVM tools such as laser scanners and laser radar, with the measured points ranging from 5×10^{-6} to 5×10^{-5}.

The previous test presented the outcomes of object volume measuring about 0.3 m x 0.3 m x 0.3 m using divergent beam FSI. The outcome of the divergent beam system reaches maximum working volume, which is due to health and safety reasons to keep the device eye-safe. The disappearance amount of beam's light indicates divergent beam FSI technology in Fig 3.33 is limited in projected measurement. A new solution of distributing the limited quantity of light is introduced to operate the projects over 10 m x 10 m x 5 m, which surpassed the limit.

The method is based on the Hilbert transform, a commonly used operation in signal processing. It is well understood theoretically (Boashash, B. 1992) and is straightforward to compute, as follows:

The Hilbert transform,

H[s(t)], of a signal, s(t), may be computed using a forward and reverse Fourier transform, multiplying the signal with a Hilbert window in frequency space,

$$H[s(t)] = F^{-1} [F[s(t)]H(w)] \qquad (3.8)$$

where F and F^{-1} denote forwards and backwards, Fourier transforms, respectively, the Hilbert

the window is defined as

$$H(w) = -isgn(w) \quad (3.9)$$

and the sgn function is defined as

$$\text{sgn(x)} = \begin{cases} -1, & x < 0 \\ 0, & x = 0 \\ +1, & x > 0 \end{cases} \quad (3.10)$$

The Hilbert transform has the following key property, which allows us to use it to calculate phase: For a signal of the forms(t) = b(t) cos Ø(t), if the spectra of b(t) is restricted to a range of frequencies that is lower than and does not overlap the spectra of cosØ(t) i.e. there exists some Wr such that

$$F[b(t)] = 0 \text{ for } |W| > Wr \quad (3.11a)$$

$$F[\cos Ø(t)] = 0 \text{ for } |W| < Wr , \quad (3.11b)$$

then the Hilbert transform of this signal is

$$H[b(t) \cos Ø (t)] = b(t) \sin Ø(t) \quad (3.12)$$

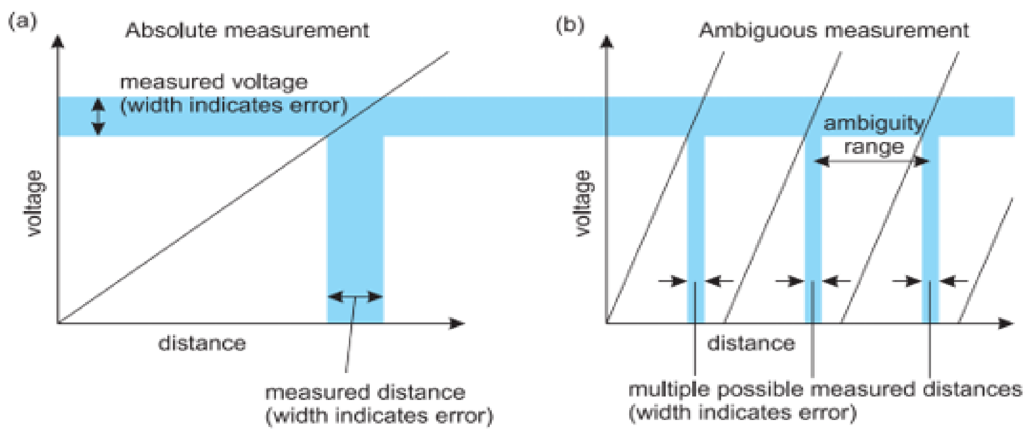

Figure 3.33 example of Absolute measurement and ambiguous measurement (Bobrof, N. 1992)

Limitations of using FSI to achieve high accuracy results in measurements as they generally measure the refractive index in a slightly different location than the path of the light beam. Therefore, we rely on the homogeneity of the air to extrapolate our measurements to this location. The test indicates parameters such as pressure and homogenises rather quickly, which is very inhomogeneous. Hence, the inhomogeneity factor leaves us uncertain on knowledge of the refractive index the measurement beam path is limited regardless of the accuracy of measurement through the test. A previous discussion on the same issue has been presented in Elter's journal (Estler, W. 1985), and the challenge of achieving measurement accuracy of 10^{-7} is nearly impossible when the working condition in the air (Bobrof, N. 1992)

Many researchers attempt to resolve the issue by estimating the speed of light along the signal path and monitoring the frequencies. Conclusion: two exemplary methods have been made some progress in resolving the problem. As Matsumoto quotes: "One method is to measure the signal delay with two different frequencies of light and make use of the dependence of the dispersion of air upon its refractive index to indicate the signal's speed (Matsumoto, T. 1992)." In addition, Korpelainen also quotes: "Another method in Fig 3.34 is to send a pressure wave along the same line as the beam and use the fact that the sound speed in air depends on parameters such as temperature and pressure than the speed of light (Korpelainen, V.; Lassila, A. 2004)."

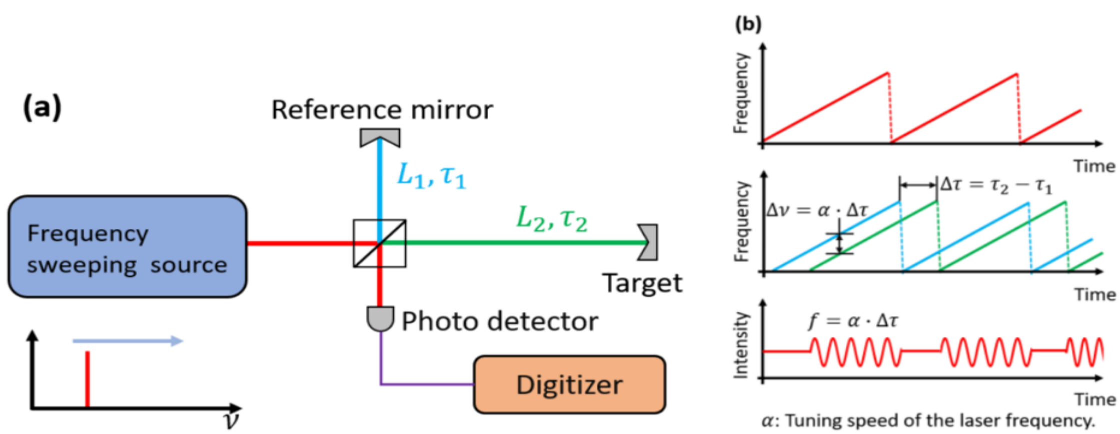

Figure 3.34 working principle of FMCW/FSI a). Schematic of FMCW system. b) Illustration of the interference fringe and frequency tuning (Korpelainen, V.; Lassila, A. 2004)

3.11.2 Bluetooth

Bluetooth technology, widely known as BT, is a modern economical technology to be used in the wireless connection among devices. Millions of devices start using a wireless connection in modern days without cables. Bluetooth technology has certain advantages such as low energy consumption and up to 20m distance mesh network. Recent research studies indicate the possibility of using Bluetooth for distance measuring based on a sensors mesh network. Internet of things, also known as IoT, connects millions of devices to form an intelligent network, a typical example of IoT technology in-home devices connected to smartphones. Bluetooth low energy technology, also known as BLE has been widely used in this application. Recent research that focuses on using BLE in measuring distance has been initiated, fully utilising BLE advantages such as low energy consumption of connecting devices and ease of use (Feretti et,.al. 2020). Indoor activity tracing in using BLE proximity can be seen as one of the innovative application research completed recently.

Bluetooth Low Energy, also called BLE structure designs, contains 40 channels with a 1MHz bandwidth at each channel space distributed between 2400 MHz and 2483 MHz to meet industrial standards. Low energy consumption is a unique feature for BLE devices which requires minimum data transfer and exchange to minimise the power consumption. There are four primary operations modes designed in the BLE structure which are master, slave, advertising and scanning (Feretti et,.al. 2020). Specifically, BLE channels 37,38 and 39 have been assigned to advertising mode, and the remaining 37 channels are allocated as data channels, as illustrated below in Fig 3.35**.**

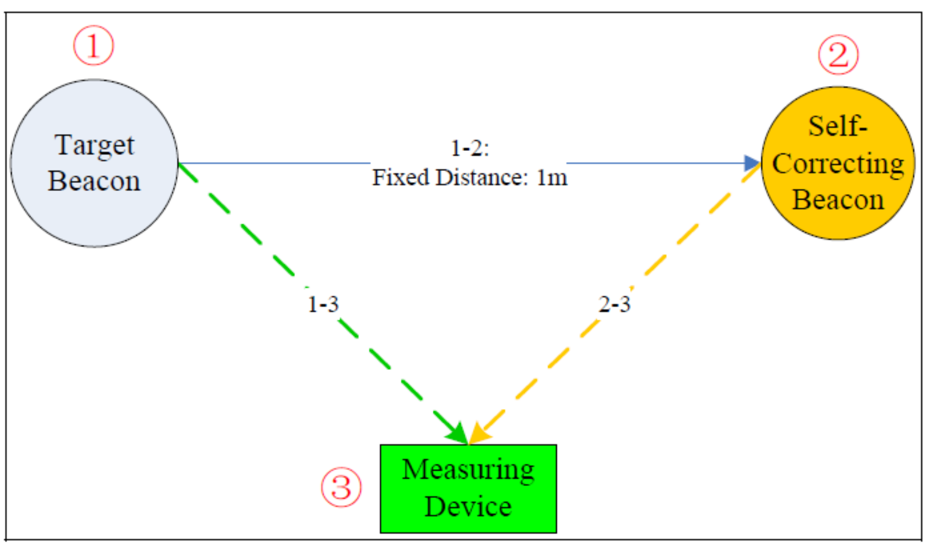

Figure 3.35 how beacon channel works (Feretti et,.al. 2020)

The BLE advertising mode transfers at variable rates by utilising short and unsolicited messages to minimise power consumption. The advertising channels generally stay at 2.4 GHz band Wi-Fi channels1, 6 and 11 to avoid interferences created from the external environment. For the purpose of minimising fading losses and interference, BLE can utilise frequency and advertising channels to meet the design efficiency.

Theoretically, BLE generates signal strength decreases with distance due to transmitter limitation. However, the invention of smartphone devices with built-in Bluetooth and Wi-Fi transmitters could measure the signal strength to estimate the distance of the source. The path loss model can be defined as the signal-dependent on an established and consistent relationship between signal loss and distance (Feldmann et al. 2003).

With the popularity of IoT (like intelligent homes) and smart devices like smartphones and smart TV, it becomes a huge demand to get the user's context for the intelligent devices to behave differently based on IoT. Moreover, location information is a crucial part of the context information. So this paper aims to resolve the measuring distance problem to achieve an accurate position in IoT. Suppose the intelligent devices could get the user's exact position information. In that case, their intelligence level could improve significantly, they can do jobs like turning on or off different lights automatically, displaying the same contents on different screens, serving the host with water by the home robot.

Currently, measuring distances can be done by specific approaches. The following descriptions give some typical possible methods (Awad et al. 2007).

1) Time of arrival (TOA): TOA finds the distance between a transmitter and a receiver via a one way propagation time by exploiting the relationship between the light speed and the carrier frequency of a signal3. However, TOA positioning requires very accurate clocks because a 1.0 µs error in timing equals a 300 m distance estimate difference. TOA is hard to popularise in

regular devices because the accurate clock can cause high costs. It cannot be used to resolve the actual measuring distances problems.

2) Angle of arrival (AOA): AOA is usually employed as prior knowledge for the triangulation localisation methods. So measuring angle is not fit for BLE on ordinary devices either.

3) Ultrasound: A mobile node with an ultrasonic sensor measures the distance to a node by exploiting the ultrasonic signal propagation time. However, the transmission range of an ultrasound signal is small as it cannot propagate further than a radiofrequency wave. It also adds size, cost, and energy supply to each device. Therefore, even though the ultrasound-based localisation approach can achieve high accuracy, it is unsuitable for IoT environments.

Received signal strength, also known as RSS, is a popular wireless sensor network used for distance estimation. The BLE integrated device such as a smartphone can be used as a transmitter to receive and send the RSS value of the signal in the virtual environment (Awad et al,. 2007). The network design can utilise the smartphone devices to improve the financial cost over large volumes of Wi-Fi routers and BLE receivers for initial set-up. Institute of Electrical and Electronics Engineers, also known as IEEE, set the IEEE 802.11 or IEEE 802.15.4 for wireless sensor networks nodes to regulate industrial applications. Below Equ 3.31 shows IEEE wireless stands comparison (Huang et al., 2017)

Antennas are a popular solution to improving radio signals transmitting via a space experiencing path losses. The assumption of the radio signal follows the log-distance path loss model. The network can predict the path loss where the signal is potential loss inside a building or densely populated areas such as stadiums over a distance. The below equation 3.98 presents the log-distance loss model:

$$PL = P_{\mathrm{T}\chi} - P_{\mathrm{R}x} = PL^0 + 10 \bullet y \bullet \log\left(\frac{\mathrm{d}}{\mathrm{d}^0}\right) + \mathrm{Xg} \quad (3.13)$$

Where,

PL is the signal strength after total path loss at the distance d measured in Decibel,

$P_{T\chi}$ and P_{Rx} are the transmitted power and the received power, respectively,

PL^0 is the signal strength after path loss at the reference distance d^0 measured in Decibel,

d is the length of the path,

d_0 is the reference distance,

γ is the path loss constant or exponent,

Xg is a standard random variable with zero means reflecting the attenuation caused by flat fading.

In the iBeacon specification, the manufacturer should add txPower value to existing BLE protocols. The txPower value is the received power at a distance of 1 meter. Then, we can replace some variables with the value of txPower. When a receiver receives a signal with txPower field, the receiver can set; d0 to 1 meter,

$$PL^0 \text{ to } P_{T\chi} - \text{txPower}$$

Then, the expression could be

$$\begin{aligned} PL &= P_{Tx} - P_{Rx} = P_{Tx} - txPower + 10 \cdot \gamma \cdot \log(d) + X_g \\ P_{Rx} &= txPower - 10 \cdot \gamma \cdot \log(d) - X_g \end{aligned} \qquad (3.14)$$

Empirical measurements could find the values γ and Xg. Android beacon library uses the following coefficients to calculate distances in indoor environments10, and we also adopted the same equation.

$$d = (0.89976)*(P_{Rx} /\text{txPower})7.7095 + 0.111 \quad (3.15)$$

Now, the variable is reduced into just two P_{Rx} and txPower. As the txPower value is fixed by the manufacturer, the fluctuation in received signal strength directly affects the calculated distance. Even if we adopt some filtering algorithms, it is also hard to determine the exact distances.

Antennas design for the portable device can be challenging as the size of antennas shall be slim and compact to fit into the mobile smart devices. Apple and Android, smart devices manufacturers, outsource antennas to fit into their devices with two common types: ceramic dielectric resonators and printed circuit antennas (Andersen, A. 2008). Commonly, a built-in Bluetooth antenna in smartphone devices performs as a receiver to pick radio signals evenly distributed from all directions. The antenna radiation pattern depends on directions from the strength of emitted radio waves.

Unfortunately, full 3D antenna radiation patterns could not perform measurement regularly due to the cost and time and shallow understanding of antenna directivity for mobile devices. In comparison to a 3D antenna, 2D radiation patterns are printed in a Sony Ericsson K750i mobile phone can perform, receiving the signal omnidirectional within about ±5 dB between 2 nulls to generate about -20 dB and -30 dB response (Rehman et al., 2010).

There is no guarantee the radio signals losses with build-in antennas smart devices through transmitter and receiver due to the line-of-sight path is through nulls in both transmit and receive radiation patterns. The key feature of mobile devices like smartphones are designed to allow end-users to move in practice constantly. A connected Bluetooth earpiece with a 30dB null in each antenna can double the loss up to 60dB during end-users directivity moving activities. The end-users are constantly rotating mobile devices in practice, which could result in a 20dB loss during the operations.

3.11.3 3D Laser scanning technology

3D laser scanning is a technology that employs lasers to measure an object's geometry to create a digital 3D model. Laser scanners measure fine details and capture free-form shapes to generate highly accurate point clouds quickly. 3D Laser scanning technology was developed in the early 1960s. Equipment such as lights, cameras and projectors were used at that time to capture the surfaces of a real-world object or environment. (OCA, 2013)

Terrestrial 3D laser scanning technology has been recognised as leading technology solution in construction surveying applications. Total station and 3D scanning laser tools can improve productivity and accuracy in many areas of surveying application such as building construction, infrastructure, landscape and more. The Machine can generate the surveying data, and the data can be recorded as references for future project progress analysis, quality control and safety management aspects. Engineering management has certain degrees of isolation to the construction site management. Even though many engineers in the construction industry are revving up processes in using building model information modelling, also known as BIM, to integrate with laser scanning technology, the manufacture discrepancy of the materials supply and human errors onsite are overwritten the machine data to create even more headaches for site construction activities.

There are mainly three types of laser scanning technology, stationary terrestrial laser.

Scanning is also known as STLS, mobile laser scanning technology known as MLS, and airborne laser scanning known as ALS. Stationary terrestrial laser scanning technology refers to laser scanning applications that are performed from a fixed point on the surface of the earth (Galvez et al., 2014). The common practice tools in the construction industry, namely total station and total robotic station, are built-in motorised laser scanning head units, also recognised as a leading solution in surveying horizontal and vertical fields. However, the cost of the tool and required trained operator slow the machinery being commonly used on site.

3.11.4 Lidar

Mobile laser scanning, also known as MLS technology, has been widely used in many applications and research study fields (Ellum et al., 2013). As one of the leading autonomous building surveying equipment, Leica adopts the MLS technology combined with Global Navigation Satellite Systems (GNSS) and other sensors on a moving device to perform the building scanning tasks with precise and accurate outcomes designers and building practitioners(Wang et al., 2019). The MLS technology is not limited to land transport devices but also applies to airborne to capture 3D data in a wide range of primary industry applications (Wang et al., 2019). The evolutionary development of MLS has recently emerged with GPS, LiDar and other inertial measurement unit technology to minimise the production cost and improve the efficiency in large scale mapping and surveying projects.

Light detection and ranging technology, also known as LiDar technology, is revolutionised in detection and mapping applications. The technology is based on light pulse emitted. LiDar technology is commonly seen in applying airborne equipment to scan large scale terrain applications. Drones, helicopters, aeroplanes and even live birds are associated with LiDar technology in performing the scanning tasks in the industry. There are marginal differences in LiDar principles between ground-based and airborne mobile laser scanning equipment. However, LiDar technology is not friendly with wet weather conditions, which is due to its nature dislike the water (Wang et al., 2019). As the leader in building autonomous driving technology, Tesla has announced to abandon LiDar technology in self-driving applications due to local weather conditions in using LiDar technology (Holgado-Barco et al,. 2014).

A target reflects the light pulse emitted by the transmitting device to the sensor, and the system calculates the relative distance between them. By scanning a surface of interest, a cloud of points is created that discriminates the points relative to the ground represented through a Digital Terrain Model (DTM) and those relative to the "objects" on the ground represented through a Digital Surface Model also known as DSM (Hadas et al,. 2016). By measuring the vegetative cover and penetrating up to the ground, information is obtained on the altitudes with centimetric accuracy.

Limitations:

Lidar technology has limitations of use in water and wet weather conditions. External environments such as rainy weather can directly affect LiDar technology measuring accuracy performance. In addition, airborne vehicles as a carrier for LiDar detectors are limited to the weather conditions, such as snow, heavy rain, and wind can directly impact LiDar detector accuracy performance.

The study of green beam laser light suffers difficulties penetrating through the topmost layer of the water column has been revealed and recognised as the top priority in generating limitations in applying the LiDar to airborne equipment. The research feedback on Single Photon LiDar constantly produces echoes during the green laser light in water column penetration processes (Degnan et al,. 2016).

The topic has been addressed theoretically by recapturing the technological principles of Single- and Multi-Photon LiDAR and reviewing laser light interaction with water.

Based on a formulation of the laser-radar equation specialised for bathymetric applications (Jutzi et al,. 2017). The designers calculated the expected number of photons arriving at the receiver for different flight mission parameters and environmental conditions.

However, there is a solution in using extra sensors combined with LiDar technology to minimise the deficiency of green light beam in measuring objectives with the water body. The added sensors can estimate the water level of the objectives and provide precision accuracy of LiDar measurement. However, a specific set-up of instruments must meet conditions of less than 50cm below the water surface with the range from 1-10m, potentially bringing the challenges in drones controlling to meet the minimum measurement standards. The good news is that 3D scanning in most building construction applications is easier to meet, excluding extreme wet weather conditions.

From processing and analysing the available Single- and Multi-Photon LiDAR datasets (Jutzi et al,. 2017), we concluded:

1. Water surface mapping is possible for both Single- and Multi-Photon Topo-Bathymetric LiDAR with an accuracy in the range of about 5cm when aggregating the near water surface echoes into 5–10m cells
2. The overall water point density is higher for Multi-Photon LiDAR
3. High-resolution water surface mapping with grid sizes in the range of 1–2m is unfeasible for Single Photon LiDAR when applying flight mission parameters optimised for topographic mapping.

Adopting Single Photon LiDAR-based high-resolution in water surface mapping applications can eliminate restrictions on measuring objectives with water surface issues. The parameter set up off drone requires below altitude to less than 2000m with ten off-nadir scan angles, which is saved in using traditional 15 scanning wedges. However, the bottom problem of LiDar does not like the water surface objective are still existed and require further research to seek the solutions (Ressl et al,. 2008). A research project based on the above theory was conducted in Germany using Leica SPL 100 to map the Rhine River's water surface objective (BfG, 2019). The findings from the project later become guidelines for flight planning, which set the foundation data for the validation of hydrodynamic-numeric models.

While accurate water surface reconstruction based on commercially available Single Photon LiDAR the technology could not be confirmed for the standing water bodies analysed in this study; better results are expected in the use as mentioned earlier case due to both the rippled structure of riverine water surfaces and the optimised flight mission parameters.

3.11.5 Ultrasonic

An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic sound waves. An ultrasonic sensor uses a transducer to send and receive ultrasonic pulses that relay back information about an object's proximity. High-frequency sound waves reflect from boundaries to produce distinct echo patterns(Riccardo et al,. 2018). Ultrasonic sensors work by sending out a sound wave at a frequency above the range of human hearing. The sensor's transducer acts as a microphone to receive and send the ultrasonic sound. Our ultrasonic sensors, like many others, use a single transducer to send a pulse and to receive the echo. The sensor determines the distance to a target by measuring time lapses between the sending and receiving the ultrasonic pulse.

To rephrase the working principles of ultrasonic in measuring distance application is relatively simple, which sends out a pulse at 40kHz, bouncing back to the sensor when the pulse reaches an obstacle or object. The distance calculation via ultrasonic is based on the speed of sound and the travel time.

The ultrasonic sensors solutions are great at liquid level measurement application are more efficient than using infrared sensors, which is struggled with target translucence. Ultrasonic sensors outperform other optical technologies in detecting objectives without influence by colour, surface, or material. Ultrasonic sensors are often used in automation tasks to measure distance, position changes, and level measurement, such as presence detectors or in particular applications, when measuring the purity of transparent material. They are based on measuring the propagation time of ultrasonic waves. This principle ensures that reliable detection is independent of the object's colour rendering or the design and surface type. It is possible to detect even liquids (Hopper, H. 2018). bulk materials, transparent objects, glass. Another argument for their use is their use in aggressive environments, not very great sensitivity to dirt, and the possibility of measuring a distance. Ultrasonic sensors are manufactured in many mechanical designs. For laboratory use, the simple housing used for transmitter and receiver separately or in a single housing, for industrial use are often constructed robust metal housing. Some types allow the end-user to adjust the sensitivity using a potentiometer or digitally. Also, the output may be in the unified version or the analogue signal directly in digital form. In the case of sensors connected via the communication interface to the PC, it is possible to set detailed parameters of all the sensor's operating range and measured distances.

Ultrasound is a technology that does not have restrictions in using any lighting environment at both external and internal environment. Ultrasonic sensors can be used in robot applications to perform collision avoidance at a slow pace movement. Today, Ultrasonic technology is widely recognised as the leading solution in grain bin sensing applications, monitoring water level, unmanned aerial vehicle application and monitoring cars traffic in a retail scenario.

Ultrasonic Sensors are best used in the non-contact detection of: Presence, level, position, distance and Non-contact sensors are also referred to as proximity sensors.

Ultrasonics are Independent of: Light, smoke, Dust, colour and material except for soft surfaces, i.e. wool, because the surface absorbs the ultrasonic sound wave and does not reflect sound (Singh et al,. 2022).

Long-range detection of targets with various surface properties.

Ultrasonic sensors are superior to infrared sensors because they are not affected by smoke or black materials. However, soft materials which do not reflect the sonar (ultrasonic) waves very well may cause issues. It is not a perfect system, but it is excellent and reliable.

Ultrasound has similar propagation characteristics in the environment, which depends on a mechanical vibration particle environment. Ultrasound propagation may be in gaseous, liquid and solids. Ultrasound is generally regarded as a frequency sound higher than 20 kHz. The ultrasound can be classified into two groups based on their applications. Active ultrasound generates high value in applying to cleaning, welding, drilling and other applications. Compared to active ultrasound, passive ultrasound generates a lower value in measuring distance detecting defective products in manufacturers. The dependency of ultrasonic technology on the temperature in changing environments can be seen in most applications.

The velocity of sound in some materials is shown in Table 3.1

Table 3.1 The speed of sound propagation in materials (Koval, et al,. 2016)

Gases		Solids		Liquids	
(m/s)		(m/s)		(m/s)	
Air (0°C)	331	AI	5100	Water (20°C)	1481
Air (20°C)	343	Steel	5000	Water (25°C)	1497
He (25°C)	965	Concrete	1700	Gasoline (20°C)	1170
H (25°C)	1284	Cu	3500	Hg (25°C)	1450
He-Helium H- Hydrogen AI - Aluminium			Cu - Cuprum Hg - Quicksilver		

This research also conducts analysis in assessing the technology capability in using portal frame measurement applications. The assessment fields of technologies in using onsite are determined as following criteria.

3.12 Determine factors onsite measure

External environment conditions; health and safety impacts; accessibility; cost and operator training.

3.12.1 External environment conditions

First of all, external environment conditions refer to weather conditions such as light, wind, water and other factors such as operating machinery, which can directly or indirectly affect measuring results. The below table 3.2 summarises all relevant factors potential affect measurement outcomes.

Table 3.2 external environment conditions for all research technology

Determine factors	FSI	Bluetooth	LiDar	Ultrasonic	3D Laser scanning	Artificial Intelligence
External Environment Conditions	Limits in light operations	Limits in distance and metal objective	Limits in surface water consitions	Limits in smoke, lights and water conditions	Limits in objectives surface reflection	Minimum external environment requirements

3.12.2 Health and safety impacts

Health and safety impacts refer to any hazards onsite that may affect measurement outcomes and potentially harm operators. The New Zealand STATS presents falling from height injuries as ranking top construction injury risks at all times. Tradition roofing measurement requires a specialist to climb to the top of the roof in order to measure rafter and eaves size. Height and harness is essential equipment in protecting the personnel from falling from height. However, not all the personnel follow the safety regulations on site in wearing height and hardness, which results in falling from height injuries. In addition, operating machinery such as cranes lifting, excavators and trucks may potentially harm the personnel operating in height. Lastly, measurement technology such as ultrasonic and laser scanning machines is high beam may potentially harm the personnel visions which cause vision loss.

3.12.3 Site Accessibility

Site accessibility refers to measurement activities access to the objectives. The equipment and personnel accessibility are critical to yield accurate measurement outcomes. Installing measurement accessories such as sensors and measurement equipment mobility can be assessed in this research as well.

3.12.4 Cost

Cost refers to any associates cost to the measurement equipment, including hardware and software, personnel competence including personnel training and installations access training.

3.12.5 Operator training

Personnel refers to the operator who intends to use the measurement equipment, including hardware and software, may require special skills sets to be able to operate the system.

Technology: FSI, Bluetooth, LiDar, ultrasonic, 3D laser scanning and AI

Table 3.3 summary for all determining factors related to affect measurement outcomes for available technology

Determine factors	FSI	Bluetooth	LiDar	Ultrasonic	3D Laser scanning	Artificial Intelligence
External Environment Conditions	Limits in light operations	Limits in distance and metal objective	Limits in surface water consitions	Limits in smoke, lights and water conditions	Limits in objectives surface reflection	Minimum external environment requirements
Health & Safety	risks in height during installations	risks in height during installations	risks in height during installations	risks in height during installations	Ground operations low risks	Ground operations low risks
Site Accessibility	Site installations required	Site installations required	Site installations required	Site installations required	Site installations required	Easy, no Site installations required
Cost	High	Low	High	Medium	High	Low
Operator Training	Required professional operator	Required professional operator	Required professional operator	Required professional operator	Required professional operator	No need professional operator

In order to determine the distance measurement technology in using portal frame length and angle applications shall follow the following factors.

1)Technical competence; 2) Challenges in setting up; 3) Environment challenges; 4) Economic cost; 5) Job site set up; 6) Limitations on codes compliances.

Above Table 3.3 is the summary for all determining factors related to affect measurement outcomes for available technology.

Summary

In summary, Artificial intelligence deep learning technology creates many advantages in using construction site measuring applications. First of all, the technology does not require any sensor to be pre-installed or installed on the sites. Weather conditions such as showering and windy weather conditions are not tasks stopper anymore, which is due to the system only requiring a camera from any capable system. Operator technical competence can be very minimum as it only requires photo shooting skills. There is also very minimum risks for the operator to perform the tasks without extra health and safety concerns such as access tools and supervisory requirements.

Regarding codes requirement, artificial intelligence deep learning technology can easily be compliant with the building codes. The initial investment in artificial intelligence deep learning systems can be lengthy and costly to build the algorithm. However, the cost could be significantly lower than any other sensor-based design system.

Accuracy of measurement is the only limitation for artificial intelligence deep learning systems in applying to this application. The system can easily meet the 20mm accuracy tolerance, but other construction measurement applications such as passive fire inspection or seismic assessment may require higher accuracy in order to meet the task's requirement. Future improvements on accuracy from the artificial intelligence deep learning system shall be recommended in future research projects. Below Table 3.4 summarises all available technology features with assessment for this research project.

Table 3.4 Summaries all available technology features with assessment for this research project

Technology	Assessment criteria					
	ternal environment conditio	Health and safety impacts	Site accessibility	Cost	erator technical competen	Limitations
Traditional roof specialist	Weather conditions and surrounding working environment can be potential risks of external environment may stop the operator working from	very risky application for personnel to work in the height and depending on surrounding objectives or hazards potential risks	Site safe pass with height & harness certs and providing machinary to access to the roof. Clearance hazards are required for operators	High in both short term and long term	Experiences in working in the height and know how to use simple measure tools.	Illness and human errors may cause more potential risks for this application. Rialiability is always a question mark for operator to perform the tasks.
AI deep Learning	Very minimum dependence on weather and surrounding working environment.	Low risk for operator to perform the tasks at distance 11m aways from the objective	Site safe pass and does not require additional equipment for operator	High in short term to create algorithm and cost will gradually decrease in long term	basic photo shooting skills in using cellular phones or camera.	Accuracy may not achieve as good as 3D imaging laser scanniong machine or Lidar technology, even achieve the tolerance requirement less than 20mm. Future improvements of algorithm system will be required to overcome other
Ultrasonic	Limits in Light, smoke and water surface operations	very risky application for personnel to work in the height and depending on surrounding objectives or hazards potential risks in	Site safe pass with height & harness certs and providing machinary to access to the roof. Clearance hazards are	Medium cost on materials but high cost on labour set up	Sensors installations and machinne operations are required professional	Require specific set up and the system requires a few sensors, sensitive with water, smoke and light
FSI	Limits in light conditions operations	very risky application for personnel to work in the height and depending on surrounding objectives or hazards potential risks in	Site safe pass with height & harness certs and providing machinary to access to the roof. Clearance hazards are	High cost initially on tools investment and reply on volumes on sensors to	Sensors installations and machinne operations are required professional	Require clear surface with flat reflections surface with least surrounding metal objectives(metal deflect the laser radio signals)
3D Imaging Laser scanning	limits in metal objectives reflection & other radio active devices on site	very risky application for personnel to work in the height and depending on surrounding objectives or hazards potential risks in	Site safe pass with height & harness certs and providing machinary to access to the roof. Clearance hazards are	High cost initially on tools investment and high labour cost	Machinne operations are required professional	the technology dislike metal and requiring decent objkective reflection points
Bluetooth	limits in metal objectives and set up distances with poor accuracy outcomes	very risky application for personnel to work in the height and depending on surrounding objectives or hazards potential risks in	Site safe pass with height & harness certs and providing machinary to access to the roof. Clearance hazards are	Low cost on materials but high cost in setting up sensors on site	Sensors installations are required professional but machinne operations does not require professional	Limits in distance set up (under 2m per sensor) and dislike the metal objectives
Lidar	Limits in water surface (rainy days) and requiring volumes of sensors to complete the set up	very risky application for personnel to work in the height and depending on surrounding objectives or hazards potential risks in	Site safe pass with height & harness certs and providing machinary to access to the roof. Clearance hazards are	High cost on both tools and sensors to set up	Sensors installations are required professional but machinne operations does not require professional	Limits in water surface operations and dislike rainy days

Chapter 4 Codes requirement

4.1 General

With no surprise, the Portal frame industry is one of the low productivity with fragment supply chain issues in New Zealand. Even worse, the industry is growing without fixing its previous issues, which causes construction materials waste and health safety concerns.

4.2 Portal frame codes requirement

Portal frame building structure codes NZS 3404 and Euro code 3 are among the top designers for designing portal frame structures. In-depth Euro Code 3 is a simple building performance code that provides designers accountability in designing the portal frame structure. The code practice ensures that the designer design steel structure includes portal frame meets seismic, and structure integrity meets the New Zealand building performance requirements (NZS 3404 part 1, 2019) and subsequently, the NZS 2728:2013 also defined prepainted/prefinished metal sheets products required for steel building structure.

Three main types of portal frame building structures are Pitched Roof Portal fabricated from UBs, Propped Portal Frame and Tapered Section or Cellular Beam Portal Frame

Amended NZS 3404 part 1 2019 defines minimum design requirements for portal frame structure designers, including seismic and building structure integration. Roofing structure as part of the structure of the portal frame buildings (NZS 3404 part 1, 2019). Subsequently, the New Zealand standard NZS 2728:2013 defines roofing materials compliance scope. In this research, the artificial intelligence imaging system defines objectives building structure based on the above building codes requirement. In addition, three main popular types of portal frame structure appear in New Zealand as follow:

4.2.1 Pitched Roof Portal (Fabricated from UBs)

A single-span symmetrical pitched roof portal frame in Fig 4.1 typically have:

A span between 15 m and 50 m

An eaves height between 5 and 10 m

A roof pitch between 3° and 5° is commonly adopted

A-frame spacing between 8 m and 12 m (the greater spacings being associated with, the more extended span portal frames)

Haunches in the rafters at the eaves and apex.

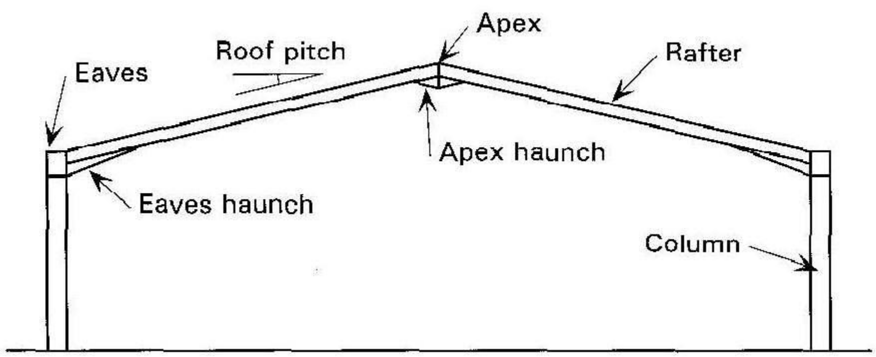

Fig 4.1 single span portal frame (NZS 3404 part 1, 2019)

4.2.2 Propped Portal Frame

According to NZS 3404, the economic benefits can be generated from both steelworks and foundations, which is due to a propped portal frame is possible to reduce the rafter size and the horizontal thrust at the base. The NZS 3404 defined that there is no need to provide a clear span where the span of the portal frame is greater than 30m.

The frame type is occasionally categorised as a single span propped portal even though the structural behaviour refers back to the category of the two-span portal frame in Fig 4.2.

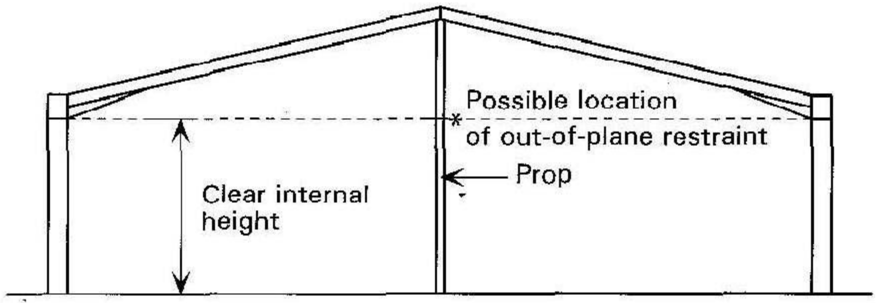

Fig 4.2 Propped portal frame (NZS 3404 part 1, 2019)

4.2.3 Tapered Section or Cellular Beam Portal Frame

Tapered welded sections and cellular beams construction methods have become popular in recent years, which is due to curved cellular beams frames installations can be efficiently completed by using cellular beams or welded sections in Fig 4.3. For transportation purposes, the splices are required in the rafter to preserve the architectural features to support the form of construction activities.

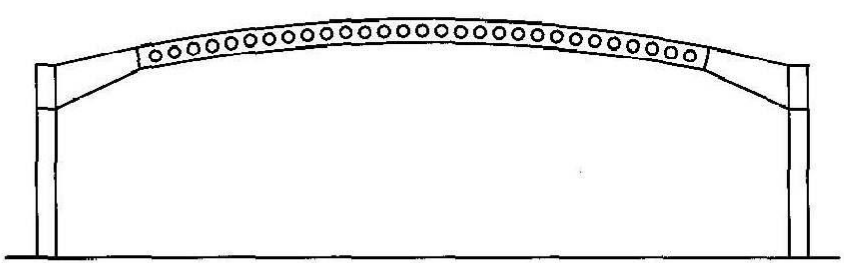

Fig 4.3 Tapered section portal frame (NZS 3404 part 1, 2019)

Elastic analysis has been stated in the NZS 3404 permits different types of structural analysis, which consists of first and second-order elastic analysis.

The first-order elastic analysis is related to second-order effects. The first-order assumptions of frames remain elastic with such tiny deflections that result from the secondary effects deflections are negligible. P-effects plays a critical role in second-order that arise from the sway of the frame, or it may arise from the deflections of individual members from the straight lines joining the members' for ends. Regarding bending moments, NZS 3404 requires first-order analysis to be modified for second-order effects using moment amplification factors to determine and calculate the bending moment. As an outcome, the procedure has been simplified in that it does not require an account for P- and P-effects according to NZS 3404 (NZS 3404 part 1, 2019).

The NZS 3404 also states that second-order elastic analysis does not require moment amplification factors but involves many iterations of first-order elastic analysis. Convergence can be obtained through the deflected shape of the previous iterations used for the second and subsequent iterations. The availability of the second-order analysis programs are expected in the market; the second-order elastic moments are generally recommended ahead of the first-order amplified elastic analysis since the second-order analysis does not require amplification.

A note reference shall be highlighted in the NZS 3404 as second-order analysis can be performed using load combination, and it is not intending in used for individual load cases. The rules applied to second-order elastic analysis to ensure its performance apply to load combinations and not individual load cases. The second-order analyses individual load cannot be superimposed where proposes using two sets of output for the second-order elastic analysis. The first-order elastic analysis performs for load cases and load case deflections, and the second-order elastic analysis takes care of member forces and reactions for load combinations.

4.3 Roofing code requirement

The behaviour of slender double diagonals in roof and wall bracing have a negligible capacity in compression. The critical components in the members are pre-tensioned rods, slender tubes and angles (Lim et al,. 2005). The assumption of diagonals behaviour in Fig 4.4 only counted for tension force from double diagonal tension bracing design. The wind loading directions also plays a critical role in determining diagonal analysis where the other diagonal is constantly ignored.

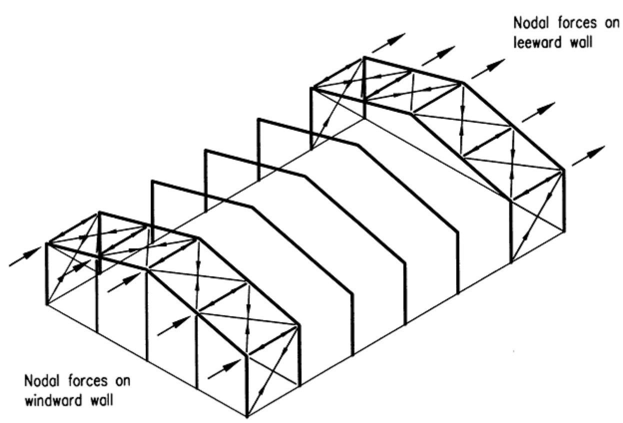

Fig 4.4 behaviour of slender double diagonals (Lim et al,. 2005)

4.3.1 Roof Plane Bracing

Roof plane bracing is placed in the plane of the roof. The primary functions of the roof plane bracing are:

• To transmit horizontal wind forces from the gable posts to the vertical bracing in the walls.

• To provide stability during erection.

• To provide a stiff anchorage for the purlins used to restrain the rafters.

4.3.2 Rafter Bracing Forces

The Rafter bracing system is considered as resisting accumulated, coincidental purlin or fly brace forces and longitudinal wind forces. The purlins in the portal frame structure act as braces when the top flange is in compression, and fly braces restrain the bottom flange in compression. However, an undefined term of bracing forces shall be accumulated and provide a rotational restrain system in utilising the purlins and fly braces together according to Clause 5.4.3.2 of NZS 3404. Restrained parallel members are no longer treated as compression flanges, and accumulating the forces are no longer required in this case, according to clause 5.4.3.3 (NZS 3404 part 1, 2019). It is worth noting that purlins and fly braces could be considered as providing restraint against lateral deflection of the compression flange. Thus, the bracing forces can be accumulated in this case.

In addition to the above accumulation of bracing forces in purlins and fly braces scenario, the roof trusses comparison in the bracing system has notably important and other key bracing components in the roofing structure. It is common to observe forces are braced back to the end bracing bays via a system of struts or ties in combining the bracing forces from the bottom compression chord of a series of larger span roof trusses where it is located under the net. Compared to the bottom chord compression, the top chord compression is braced by purlins back to the end bracing bays. There is no requirement of using accumulated forces where top chord compression contributes by gravity loads, and the bottom chord compression contributes by longitudinal wind forces. Hence, the top chord compression loads become not critical anymore on end bracing bays.

Similar scenarios of top and bottom flange bracing forces also apply to UB and WB when the flange is in compression, and accumulation forces are considered in this case. However, the accumulated bracing forces play a small role in the total longitudinal forces for entire portal frame buildings when the lateral argument is accepted. Therefore, the accumulated bracing forces in the roof and wall bracing bays are no longer required by designers to consider UB and WB rafters.

According to NZS 3404, designers commonly design pre-tension actions between 10% and 15% of the yield capacity. It is necessary to inspect the behaviour of pre-tensioned rods like cables whose self-weight is carried by tension alone. The yield capacity of pre-tension is sufficient due to the pre-stress level being not practical to measure or control in reality. The long rod tension load play a critical role in many stress levels. The rod behaviour in pre-tension generates very little force to reduce the sag until the sag gets to nearly span/100 (Gorenc et al, 1996). surprisingly, the design of a 20-meter cable only requires 20MPa to reduce cable to the L/100 deflection. The stress levels may increase much higher in practice compared to design scenarios.

The University of Queensland conducts a few laboratory experiments examining the long rod tightening behaviours ranging from 12mm to 24mm with 13 meters length. Technicians were instructed to tight one end of nuts with a spanner to measure the force in the rod with a calibrated proving ring connected to the other end (Woolcock et al, 2011). The outcome of these experiments presented that the average level of pre-tension rods are exceeded 10%-15% suggested pre-tension force (Gorenc et al, 1996). Notably, 16mm diameter rods performed exceptionally well, which generates between 40% to 55% of their design tensile capacity. Hence, a 20-meter span design scenario can resolve excessive sag issues.

The ultimate tension loads capacity of the rod does not interfere with the presence of pre-tension force. There are several key factors that need to be considered in roofing structure bracing design. The rods loading capacity limit are greater than the dynamic tension diagonal under serviceability wind load, which is the extent to relieve the pre-tension yield in Fig 4.5. In many cases, the turnbuckle sections reach their limit failure prior to the rods exceeds to its limit failure capacity (Woolcock et al, 1999). There, the designer should consider the factor of connections fracture capacity is equal to or greater than the ultimate or fracture capacity of the rods to the design of roofing structure bracing system. "The bigger, the better" design concept may lead to opposite outcomes in this case. A typical 20mm diameter rod is over-designed in many cases where a 16mm diameter rod meets the design requirement. The traceable clause can be found in Clause 9.1.4(b)(iii) under NZS 3404.

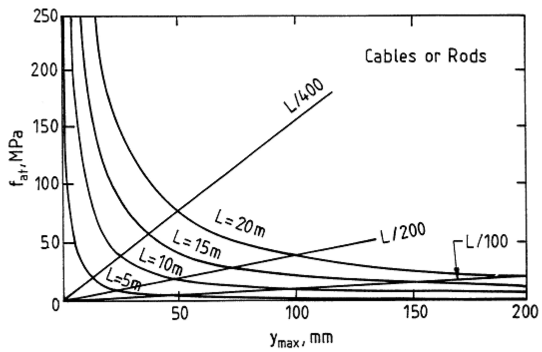

Fig 4.5 Effect of Axial Stress on Cable and Rod Deflections (Woolcock et al, 1999)

There is a potential risk of overloading the struts by pre-tensioning activity in Fig 4.6. Pre-inspections on rods size design are essential to avoid the oversize design of the struts to cater for forces in the diagonals due to combined pre-tension (Woolcock et al, 1999), and wind load may cause further issues in construction activities.

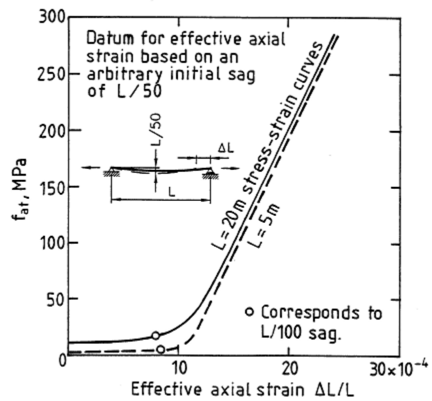

Fig 4.6: Effective Axial Stiffness of Cables and Rods (Woolcock et al, 1999)

4.4 Tubes and Angles in Tension

The designers shall consider that tubes and angles are difficult to pre-tensioned and must meet the size as beams to limit self-weight sag in comparison to the design of the rod. Self-weight bending on tensile capacity and the deflection limits are vital factors that need to be considered by the designers in order to achieve better outcomes of building structure design. The contrast of engineers design reflects oppositely, one group of engineers combine self-weight bending actions with axial tensile actions where the rest ignore the bending actions completely.

Woolcock theoretically presented that self-weight bending has a little or marginal effect on the fracture capacity of a tube or angle. Self-weight bending moments actions are reduced, followed by the tension increases (Woolcock et al, 1999). In conclusion, designers shall not consider self-weight bending actions combined with axial tension.

There is a proposal for the designer to avoid excessive slack where it is advisable to limit deflections to span/150 to avoid lack of fit without propping during erection and aesthetic reasons. There is a concern for the construction industry as the sag can be pretty evident if one sight is along with the member and not installed evidently from floor level.

Designers have options in designing purlins with flexible diagonals to be installed before the purlins are in place. The designers may face the challenge of designing the stability of the portal frames without bracing. The installation of lifting the diagonals into the place can be challenged when purlins are erected first due to obstructed by the purlins. The cost-saving action can be reversed when the extra labour required to drill and suspend is greater than the material saved. Considering all these factors, suspending very flexible diagonals from purlins is not recommended.

4.5 Flashing and gutters requirement

Fifty years of the durability of flashing materials, including unseen gutters and other relevant materials, are specified in the New Zealand building code.

AI Imaging technology can close the gap of health safety and building codes require.

Implications of using Artificial intelligence technology to perform initial measuring vital elements, including rafter, eaves, apex, and roof pitch, can provide better data accuracy for roofing manufacturers and installers. In addition, the measuring processes using artificial intelligence can reduce the risks of working in the height and weather conditions causing process delay. The site measurement in artificial intelligence imaging is a better evolution solution than traditional tape measuring.

Summary

In summary, roofing code compliance plays a crucial role in ensuring the portal frame structure remains elastic and complaint to NZS 3404 based on Euro code 3. The roofing code shall comply with NZS 2728 to ensure the roofing sheet and other relevant components meet the industrial standard. The upgrading processes are essential to maintain the industrial standard to keep the building structure safe and sound. Some other relevant design, such as seismic and wind load, also requires engineers to consider the pre-construction phase. The industry shall be guided by researchers to improve the industrial standard continuously.

Chapter 5 AI Imaging technology in using construction industry market opportunities

5.1 General

Artificial intelligence technology rapid growth brings many benefits to the community, especially in the construction industry.

Artificial intelligence is very familiar to most researchers as the first formal institulisation of AI was introduced to academics in the 1950s. However, Ancient Greece philosophers initiated the discussion that reproducing human skills began well before Leibnitz and Pascal were classic representatives who passed through science fiction fantasy and innovative mathematicians. Following the human cultural development, classic three periods of accelerated development, above all in the methodology, intermitted with the disinterest towards the discipline due to the limited deployment of the first intelligent machines (Buchanan 2005).

Modern days, the environment is changing at a rapid rate. Artificial intelligence could dominate the technology revolution and become pervasive technology on a global scale by utilizing its unlimited and economical storage and access to the global network (Ransbotham et al. 2017). AI has already started shining as the leading expert in changing the world with a radical innovation destined.

AI has multiple effects with its development and adoption to the world, which shares similar technology revolution of electricity and internet inventions. The economic consequences of AI development is a possible measurement since it is impossible to consider every single aspect of such a change (2018; Chen et al. 2016; Furman and Seamans 2019).

AI has been recognised as the key enabling technology of the new social-economic system; Facebook and Tiktok are typical companies heavily in using AI technology to change people's daily lives in the world. Every technology has a downside, AI has its weakness over the positive impact on the social-economic system. Therefore, three categories have been identified as primary, secondary and tertiary in analysing AI usage in modern days.

5.2 Artificial intelligence technology in social economy implications

A few predictive research have been conducted in studying the artificial intelligence impacts on economic consequences. The tremendous statistical survey made by a multidisciplinary group from Oxford and Yale in 2017 stands out from all others. "Advances in the field of artificial intelligence", states the abstract, "could transform modern life by reshaping transportation, health, science, finance, and the military. To adapt public policy, we need to anticipate better these advances" (Dafoe et al. 2017). 352 AI study researchers joined the interview and shared their feedback on developing high-level machine intelligence (HLMI) within the next 100 years. *High-level machine intelligence* is defined as a point in the future "when unaided machines can accomplish every task better and more cheaply than human workers."

The research also interviewed a subset of participants who shared their opinions on complete automation of labour (FAL), intended as a complete replacement of people by machines in every working position. The outcomes from the research presented that the forecasts of full automation are more aligned to the future than HLMI, with a 50% probability of reaching the FAL within 122 years and a 10% probability of reaching it within the next 65 years, starting from 2016.

Fig 5.1 presented that complete autonomation is far from being reached in reality. The typical working field, such as the surgeon, whose tasks, with an aggregate estimated probability of 50%, could be thoroughly carried out by the machines within the next 35 years. "Advances in artificial intelligence have massive social consequences", claims the study. "In addition to possible unemployment, the transition could bring new challenges, such as rebuilding infrastructure, protecting vehicle cyber-security, and adapting laws and regulations. Every innovation, including AI technology, requires a regulation to minimise the potential risks of relacing human beings work completely in the future. The AI developers and policymakers could also arise from applications in law enforcement, military technology, and marketing.”

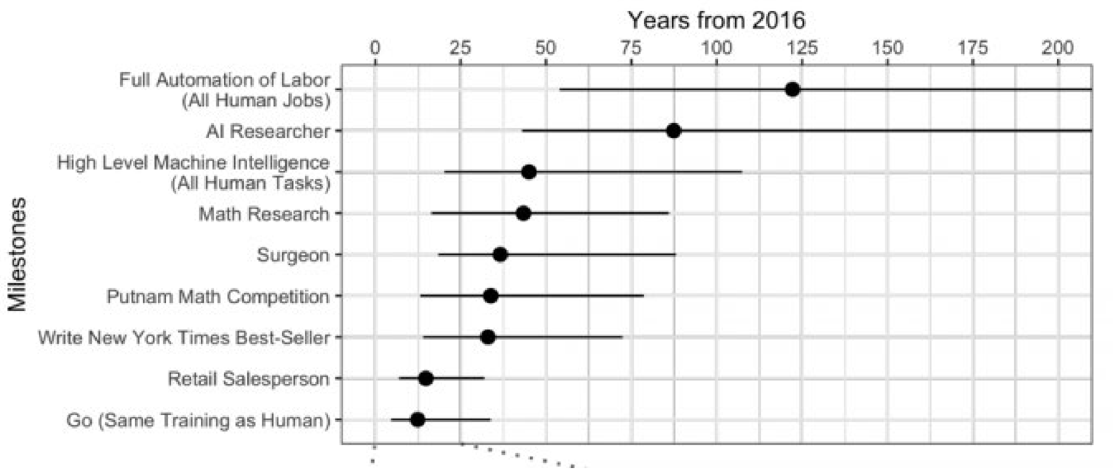

Fig 5.1 The predicted onset of the full automation of labour (Grac et al,. 2018).

Accenture is one of the world's largest multinational business consultancy companies, whose research outcomes concurs the previous research result in the same year (Daugherty and Purdy 2016). According to the Accenture report, the two traditional drivers of the economy, capital and labour, can no longer replicate the increase in prosperity that occurred in previous decades in most developed countries. Artificial intelligence, therefore, represents a new factor of production capable of transforming the basis of economic growth throughout the world in Fig 5.2.

Fig 5.2 Accenture: TFP is a total factor productivity (Daugherty and Purdy 2016)

There is marginal space in the research focused on the social cost of the estimated increase in growth rates, especially in studying how intelligent machines could replace human operators in all working positions. Nevertheless, the report highlighted the importance of "facing and anticipating the negative consequences of AI" by policymakers. The author remains confident that AI would not replace the labour and capital as main economic growth generator, but enabling them to be used much more effectively". The report also highlighted the assumptions of the AI growth model, which is proposed by a constant long term employment rate, a postulate questioned by the results of the statistical survey examined previously.

5.3 Gin, Television, and Cognitive Surplus

Gin Graze refers to a period of gin consumption were surpass the general food grocery consumption for Londoners in the 18th century. The period of Gin Graze leaves a famous century comment on this period" the Distillers have found out a way to hit the palate of the Poor, by their new fashion would compound Waters called Geneva, so that the ordinary people seem not to value the French-brandy as usual, and even not to desire it". The British parliament had to pass five significant Acts in 1729, 1736, 1743, 1747 and 1751 to control gin consumption. However, the acts could not stop the black market from selling gins, which caused the most significant public concern in British history (Defoe, D. 1727). Researchers like Shirky refers to the Gin Graze as an older version of modern-day concern. How society deals with free time to technology has become a significant concern since Gin Graze in the Industrial revolution period and Sitcom popularity in TV since the second world war until modern population donate their spare time to the Internet social media. Most people common sense in terms of how the technology is determined by the tool or medium itself. The network of technology provides a channel for users to access one another. A typical example of a program called Ushahidi to assess how people respond to using their free time for plentiful commodities is called a cognitive surplus. The program was performed to develop to support citizens to track differences in the diverse ethnic group reaction to violence in Kenya. The outcome of the research program discovered a wide geographical area due to cognitive surplus. The powerful resources were created by collective people from the community indeed overwrite people's imagination of the impossible in using the cognitive surplus in the past. Shirky was the first person who defined that human beings have to be responsible for making the media meaningful and valuable to add value to it. The human beings collectively are not just a source of the surplus; the human beings are also the people designing its use by our participation and by the things we expect of one another as we wrestle together with our new connectedness (Shirky, C. 2010).

Coincidentally, the New Zealand TV population is up to 53% of the entire population, and each person average TV viewing time is collectively 23 hours per week (STATS 2021). Which implicates how much spare time average Kiwi would like to spend viewing TV. The impact of media on the personal lives of civilians, companies, and governments. Modern-day platforms such as YOUTUBE, Tiktok and Tweeter can be used by anyone, compared to the fifteenth-century technology such as photographic plates, CDs, Radio, and Television. Four main facts of motivation for people who are using social media platform has been summarised by Shirky (Shirky, C. 2010), which are

1) increased competence,

2) autonomy over what we do,

3) membership of a group who share our values and beliefs,

4) the sharing of things with that group.

The intention of applying the social media platform is to reach a vast audience s who share common interests and motivations. The digital platform provides an essential resource to connect people to share and learn quickly. It is clear to see the evidence indicates the digital and Internet era takes prominent group people away from the television to start playing play digital social media platforms such as Facebook, Youtube, Wechat and Tiktok. Smartphones invention makes people start playing social media more intensively than ever.

Shirky explores further discoveries of the cognitive surplus could not define the new uses by means and motives from human beings. However, human beings are willing to take opportunities as the motive. Human beings are easy to discover unconventional routes to benefit society. Shirky uses one example of older people adopting the Internet as new communication tools and search engines, and young people use a skateboard to adapt them into the drained pools into skating ramps. The last swimming pools example proves the intended capabilities of something does not determine its functions; later, Shirky uses Ultimatum Games to explain that a proposer and responder are given tasks of splitting ten dollars (Shirky, C. 2010).

The main concept of behavioural economics is that proposers intend to split heavily favours them; on the other hand, responders intend to accept it regardless of how small their share is (Lin, T. 2012). Practically, responders tend to reject unfair proposals while the proposers tend to offer fair deals. Therefore, rewards and punishment appear at some level in a social situation to seek fair justice. Shirky also mentioned that the Public sector is popular, designed to enrich society without any financial incentive. The social internet platform provides an opportunity for people globally to connect to share their thoughts and work when they normally could not. The gatekeepers have been removed from the digital network to encourage people to be innovative and creative; the younger generations can find their voice there in a rapidly changing environment.

Post-World War two era did not just bring mental trauma to the people suffering during the war but also transformed society. The Success of Open Source was written by Steven Weber's that lesser costs nor technical quality are worthy explanations for why someone would collaborate on an open-source project. Shirky took notes from the above two key facts and summarised a paradox in a revolution in which human beings can change the future of the previously-existing society. Shirky has also discovered that a computer system called PLATO in 1960 provided a media platform that revolutionised human conversation was an ancestor of today's electronic devices (Shirky, C. 2010). SixDegrees was the first social networking website prior to Facebook and Friendster being introduced to the world, and as a result, there is revolutionised responses from the people who can share their conversations easily with local and offshore connections. Shirky states the success opportunity should start with a small goal, ask questions and that behaviour is in pursuit of it rather than impractically start complex.

5.4 Construction industry market analysis

5.4.1 Opportunities in applying AI imaging technology to construction supply chain operations

The Covid pandemic also impacts the labour force in New Zealand due to two main reasons. The migrant policy restrictions and changes in domestic labour force career selection may impact the company's sourcing decisions. The New Zealand market and population growth are likely to bring migrants to support the domestic labour market continuously. The domestic construction labour market has already struggled to meet the demand of the booming market since 2017. The range of short labour lists ranges from structural engineers architects to tradespeople such as carpenters, plumbers, and electricians. Special skills sets with relevant domestic certifications restrict many people's job applications competent with the trades without domestic certifications. Even worse migrants, the pandemic slows down the migrant applicants and almost seized opportunities for trades and professional people willing to come to the New Zealand border. The

New Zealand economic development is moderately reliant on migrants skills and investment to develop the domestic economy. An aging population and low birth rates in New Zealand extend the labour shortage issues to all industries, especially in the construction industry.

The Fig 5.3 indicates the numbers of the New Zealand trades and professional people shortage and forecasting in the coming years (NZ Stats 2021).

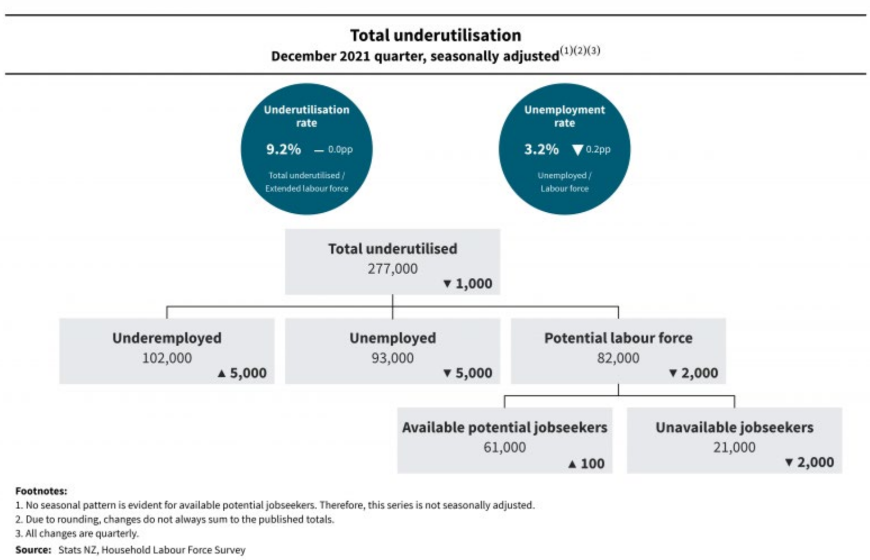

Fig 5.3 Labour utilisation NZ (STATS 2021)

The vaccination processes are bare to meet the requirement of recovery speed, which costs the nation financially and leaves slim window opportunities to open the borders. The unvaccinated population may bring more government concerns in allocating the personnel resources into the required fields in the community, which may result in further labour resource loss. Artificial intelligence technology can indirectly support these vital labour forces in offering specific jobs without vaccination requirements.

Construction Supply Chain Management (CSCM) is defined as "a system where suppliers, contractors, clients and their agents work together in coordination to install and utilise information in order to produce, deliver materials, plant, temporary works, equipment and labour and other resources for construction projects" (Hatmoko & Scott, 2010 p.36). The manufacturing supply chain management is also known as MSCM, which shares some aspects inspired to CSCM with substantial and marked differences in principles (O'Brien et al., 2008). MSCM focuses on modelling production volume, which lacks coordination of discrete materials quantitates in aligning engineering services to deliver quality projects in specific areas (O'Brien et al., 2008).

On the other hand, supply Chain Management, known as SCM, has a holistic systems view of the production activities of autonomous production units, including subcontractors and suppliers, to seek global optimisation of these activities. Therefore, the SCM weltanschauung is that system performance supersedes individual operation optimisation. (O'Brien, 2000). Compared to the hierarchical approach of traditional methods, SCM allows planning, controlling and contracting for the projects to be optimised separately. The main goal in using SCM continuously improves the system in both production costs and capabilities

in order to integrate the system to tailor the needs for the company with a deep understating of its situation. The process provides a rational basis for understanding the company to improve full production coordination and control on construction projects. An improved production system can benefit financial cost improvement where contracts can be formed to optimal supply-chain performance(O'Brien, 2000).

The construction industry has a long history of facing supply chain issues in the following aspects: materials, labour, information, plant, equipment and temporary works from various parties. A construction supply chain management has been introduced to the construction industry in order to resolve the issue. SCM includes a wide range of related discipline areas (Hatmoko & Scott, 2010). The impacts of CSCM practices on many projects are measured and documented for future research study references. Many critical items in the CSCM study, such as quality rates, inventory, lead time and production cost, must be measured. However, only logistical issues have often been treated as critical matters in the CSCM study (Vrijhoef & Koskela, 1999; Vidalakis, Tookey & Sommerville, 2011). Relationship study in CSCM has been conducted between contractor, subcontractor and supplier can explore other issues such as conflicts of products cost, labour rates, pre-construction contracts and extra cost ownerships will directly or indirectly impact all parties. In addition, many more theories like just-in-time (JIT) practice (Koskela, 1992; Tommelein & Li, 1999), the economic perspective of CSCM (Spinler, Huchzermeier & Kleindorfer, 2002), risks in SCM (Kara et al., 2008; Yim et al., 2011), decision making in CSCM (Nemhart, Shi & Aktan, 2005; Kaare & Koppel, 2010) and costs (O'Brien, 2000) have been mentioned throughout CSCM studies.

The CSCM is a leading supply chain solution to the current construction industry and addresses the wide-ranging themes through the research. However, studies seem to lack attention to the effects of clients on CSCM strategies and implementations. The gaps in pursuing clients' opportunities from many CSCM authors must be addressed. In many cases, construction clients such as developers face many issues on over budgeting, delaying projects, and poor quality of constructions delivery. The clients play critical parts in the entire construction process who create demand for the built product and provide the finance essential to sustaining opportunities for the construction industry. As the final analysis of the CSCM studies reflects, the clients are the decision-makers on fulfilling the expectations regarding time, cost and quality.

Furthermore, the focus of the CSCM on investigating clients roles and their needs on the timing of investment and any related decisions on project delivery becomes crucial in most construction projects. Any construction project is expected return on investment, also called ROI, which can benefit the clients at the end of the project (Pearce, M. 2016). The ROI is associated with many elements generated from the construction activities but not from time, cost, and quality. Therefore, the need in providing a financial assessment tool to the client can impact the CSCM decision making. Consequently, the economic value proposition of CSCM seems possible logical to the clients who make the final decision on construction activities from their perspectives. For instance, a perfect project shall start meeting or under the clients lead time expectation due to the project lead time being based on their forecast on the external economic environment to assess the probability. Any supply chain failures could potentially cause significant investment loss due to a bad economic environment bringing the value of properties downturn.

Researchers like Vrijhoef and Koskela (1999) discovered the construction supply chains remain problematic as significant issues with both bodily waste and cost are continued to rise. The construction industry still faces issues because the CSCM focuses on effects rather than the cause. Typical examples of the current New Zealand building industry is facing limited suppliers products are" approved" or "compliant" products and alternative selections of better or similar products are virtually non-existence. Hence, the "oligopoly" and "monopoly" supply chain game can benefit minority suppliers in the long run but leave marginal economic value to the domestic construction industry. For the last decades, the New Zealand gypsum boards supply has been dominated by GIB, a Fletcher Building Group subsidiary company. The short supply with inflated pricing of the gypsum boards during the Covid pandemic can quickly impact the client's delivery lead time and significantly inflated cost. Alternative gypsum boards products solutions from offshore to resolve the situation are blocked by ironically local aging construction standards. Even worse, the cracks of the problem are deepened further by New Zealand fragmented construction supply chain and limited options for procurement tendering processes.

Vrijhoef and Koskela (1999) explore many ideas to improve CSCM based on SCM application. Their study highlight three key ideas to improve the CSCM:

1. The SCM methodology can be redesigned by reconfiguring the supply chain's structure for each project under consideration.

2. According to the new configuration, controlling mechanisms need to be implemented to coordinate the supply chain.

3. The system has to be reviewed to make continuous improvements.

The ideas are trendy and have been widely recognised by many authors (e.g. Kara et al., 2008 or Kaare & Koppel, 2012). Vrijhoef and Koskela's view has been approved by Christopher and Peck (2005), which is that potential opportunities can be created for a resilient supply chain. Further studies of cultural risks management assessment with creating a sustainable supply chain were completed by Christopher and Peck (2005), which is also a critical study field that may impact future supply chain management. New Zealand construction industry supply chain's fragment is related to organisations culture, projects poor planning and procurement driven by cost rather than pursuing an opportunity to improve overall productivity and lead time. Portal frame roofing installation can be a typical example of how company culture can influence the project's outcomes. The main contractor has certain powers in determining which subcontractors and the products for the project. The main contractor could generally select the cheapest cost of the tendering suppliers and sub-contractors. This culture may result from poor installation quality due to inaccurate measurement, stocks availability, and labour skills not meeting the standard. An outcome is that the roofing installation quality may appear leaky, which reflects the financial cost and may go back to the client. In addition, on several occasions, limited numbers of roofing suppliers in New Zealand could not meet the supply due date due to manufacturing capacity and operations remains problematic.

New Zealand is leading to producing innovative concepts and products in the region with relatively small population size. New Zealand could potentially become a leader in construction supply chain management theory if the research program can be adopted. The New Zealand construction industry has rapid growth in volumes of projects. A covid pandemic could slow down the building properties building consents applications, and the numbers are growing (Aday S, Aday MS. 2020). New Zealand construction is currently facing a massive gap in supply chain issues, and a research program in this field is a must. Other offshore research programs that lead to success in practice demonstrate that New Zealand's possibilities can follow the steps in resolving current construction supply chain issues. The success story of the Just in Time concept from Japan proves that supply chain management study can lead to massive success in the industrial revolution.

Real Option, known as RO, is one of the key concepts from SCM, which incorporates managerial preferences and flexibility into the decision making. The concept is based on financial industry theory from the clients perspective, which integrates into the CSCM with the added value of flexibility to the projects (e.g. Spinler et al., 2002; Yim et al., 2011; Nembhart et al., 2005). The RO concept can apply to a wide range of investments in the construction, mining, oil, & gas industry. RO provides a deep dive CSCM analysis from clients' perspective, which evaluates pre-construction and post-construction activities.

RO has been considered one of the leading evaluation tools in supporting clients in making viable financial decisions, especially in uncertain environments (Nuefville, 2003; Birge, 2012). The New Zealand property market faced an economic downturn from 2008, and consequently, many property developers went down bankrupt. The RO has significant advantages over the Net Present Value method in evaluating the financial situation in a constantly changing environment to predict potential gain or loss from clients' ROI perspectives. The method can also improve current and future cash flow situations.

In addition, RO also provides added value for flexibility to the management team to decide alternative company's operating strategy to meet constant changes environment. The management group can utilise current capital to favour future opportunities on the company's expansion, contracting, and abandoning the projects at different stages (Trigeorgis, 1996). The management flexibility in operating can also impact supply chain management and alter different operating strategies to meet the project goals (Martinez, 2009). The New Zealand construction industry constantly faces financial challenges directly impacting supply chain management operations. The majority of clients use the NPV method over RO to monitor their financial status for the project. The project over budgeting is very often seen in the New Zealand construction market, which directly causes clients to be underpaid or abandon the pay to the sub-contractors, resulting in new conflicts to the project.

5.4.2 Social surplus labour and surplus value

Dr Karl Marx defines surplus value as the difference between the amount raised through a sale of a product and the amount it costs to the owner of that product to manufacture it. (Cox & Townsend, 1999) the theory well defined. The surplus value indicates capitalists profit based on cutting workers benefits and wages. The theory explains the massive production industry period logically dated back to the 17th century but missing one of the critical elements of technology evolution, and entrepreneurship contributes to the surplus-value to the community, not just workers themselves. Artificial intelligence technology development is one of the leading examples of demonstrates end users can widely use technology without tertiary education.

The construction industry is globally critical as it contributes 10% of the world's GDP and 7% of its total employment. Also, 40% of annual natural resource consumption, 30% energy consumption, and 25% of all timber consumption are from construction (United Nations Environment Programme, 2010). Further, MarketLine (2013) estimates that the global construction materials market in 2013 had a value of $1.031005 trillion, a 37.1% increment in 2012. The industry is project-oriented, complex and uncertain because it is fragmented, trading relationships are short, information flow is weak, and there is a significant dependence between tasks and activities (Briscoe & Dainty, 2005; Wegelius-Lehtonen, 2001a). In line with this, Pryke (2009) explained that the construction industry is characterised by fragmentation, adversarial relationships, project uniqueness, separation of design and construction, and competitive tendering, based on past research conducted in the UK.

Fragmentation causes poor performance in the entire supply chain (Egan, 1998; Latham, 1994). Adversarial relationships in the supply chain occur as different project participants' needs are contradictory. For example, a client's primary goals are low cost and high quality, the designers' and consultants' primary goals are high fees and acceptable quality, the main contractor's primary need is profit maximisation, and subcontractors and suppliers look for on-time payments (Cox & Townsend, 1999). These primary goals show contradictory behaviour. As construction projects are usually bespoke, each project's resource requirements, specifications, and technologies are different. Therefore, each project is coupled with discrete demands, and subsequently, supply chain relationships tend to be temporary.

Communication plays a significant role in sharing information accurately and efficiently (Hu, 2008) across any supply chain. Therefore, the key to effective collaboration in the supply chain is good communication between the various supply chain stakeholders. The supply chain system attached to a construction project is complex; numerous supply chain clusters overlap with other clusters. The main objectives with a limited number of designers, materials suppliers, or components are to design and deliver a substantial, recognisable element of the overall building, reduce costs, improve the value, and minimise waste (Nicolini, Holti, & Smalley, 2001). Further, clusters are considered semi-independent groups of the project, and they are under the overall coordination of the project management team.

Adopting Artificial intelligence technology into the New Zealand construction industry can improve communication among key stakeholders. A consistent and unified communication shall be established with the designers, manufacturers, and installers. Variable inputs from installers and designers can turn into unified data to the suppliers and manufacturers through artificial bits of intelligence technology.

Measuring objectives using artificial intelligence has excellent future applications, which is extended from roofing structure measuring to other relevant measuring objectives within the building.

5.5 AI Imaging technology limitation

The artificial intelligence's limitations can be found in von Neumann's last published research paper, "The Computer and the Brain", where the possibility of replicating human brains to replace artificial intelligence technology would fail. The simple answers explained that computers require arithmetical precision. Brains do not. The nervous systems of living organisms have evolved to interpret and act upon vast quantities of ambiguous information without relying on computational accuracy. In addition to the principle of the possibility of Human concerns on artificial intelligence technology can replace the human brain in almost every aspect, von Neumann states in the paper, "A deeper mathematical study of the nervous system may alter our understanding of mathematics and logic." Von Neumann's paper implies that artificial intelligence technology is based on mathematical, logical theorems with digital inputs where the human brain nervous system is analogous with motions and thinking ability to adapt to changing environments.

Artificial intelligence deep learning technology plays a significant role in stringent science research applications to assist human beings in constantly improving productivity and performance. However, artificial intelligence technology has limitations to apply to specific applications such as entertainments creations and novel writings, which is due to the deep learning technology itself cannot biological and emotional function as a human brain.

Artificial intelligence has been criticised as replacing human beings in many areas (Dafoe et al. 2017). However, the only proof that AI deep learning technology can replace human beings is using electricity energy fields to run the system (Thiel, P. 2014).

Chapter 6 Conclusion

The concept of a novel Artificial intelligence deep learning technology in measuring portal frame roofing structure was developed to improve health & safety, quality, and productivity under demanding construction environments. The proposed system consists of real-time measurement and calculated roofing area outcomes via the cloud-based system to support roofing manufacture production line and design planning. The system is not limited to reducing the safety risks of site measuring personnel but also sets a benchmark measurement quality through artificial intelligence deep learning capability.

Artificial intelligence deep learning technology in a portal frame measuring research project presents the accuracy of the measurement can achieve less than 3% compared to current traditional methods. The proposed artificial intelligence system has improved the current building survey personnel's professionalism requirement. Special training and pre-knowledge in surveying are no longer required in the future. The concept of artificial intelligence deep learning provides a solution to the trades labour shortage in the construction industry, which highlights low population density and imbalance of population resident issues in New Zealand.

Artificial intelligence deep learning technology provides a leading solution to site measuring applications, outperforming existing technology, FSI, Bluetooth, 3D Laser scanning, Ultrasonic and LiDar technology in all five external environment conditions, health and safety impacts accessibility, cost and operator training aspects.

Social-economic benefits in using artificial intelligence deep learning technology in the construction industry can be proved by leveraging available labour resources and surplus-value in the community without special training or tertiary education backgrounds.

In the pandemic, global supply chain challenges can be significantly seen in two main areas; rising cost and short supply have been among the top global supply chain challenges since early 2020. Portal frame measurement using artificial intelligence deep learning technology proves a positive research direction to solve the modern problem using the modern solution. The real-time calculation can advance manufacturers' current site productivity and design planning.

Artificial intelligence deep learning technology development is not intended to replace humans but to become a perfect partner in collaborating with human beings to create values in the community.

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