The Impact of Emerging Technology on the Value of Construction Projects

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Abstract

Up until around the 1960s, construction methodology had not changed much. Since then, starting with the entry of computer aided design, emerging technologies have presented new ways of completing tasks. This is timely as conventional construction method efficiency has plateaued, leaving room for improvement. Key emerging technologies that have entered the industry in recent years include 3D printing, artificial intelligence, augmented (mixed) reality, building information modelling (BIM), drones, mobile technology, robotics, and virtual prototyping. All these technologies offer perceived value by means of increased efficiency, however the important question brought forth in this research asks whether these emerging technologies increase the value of construction projects. One key finding was that BIM was a foundational technology for some of these mentioned here. However, overall, the findings were incomplete and future studies are needed to further explore this topical area. Siloing each emerging technology and gathering primary research from real projects that employ the emerging technology is critical. From there, information can be gathered on time, cost and quality efficiencies versus similar, historical projects in order to use data to tell whether actual value has been provided by the technology being studied.

Keywords: *emerging technology, construction, BIM, value, time, cost, quality*

The Impact of Emerging Technology on the Value of Construction Projects

1. Introduction

In this day in age, every industry has experienced some sort of transformation due to the introduction of technology. The construction industry, albeit slower to adapt to technological changes, started to make a transformation from the 1960s onward, specifically by means of introducing new manufacturing techniques and large-scale prefabrications. From the 1990s forward, robots used for design purpose and single-task robots to carry out individual tasks are the newest type of technology seen implemented in the industry. However, despite the technological advances made to date, the construction industry's performance on projects has plateaued. Conventional construction methods will not increase performance output on projects moving forward, unless further technological advances are adopted (Bock, 2015).

Given this information, there is a big opportunity for players in the construction industry to adopt emerging technology (ET) to increase automation to increase performance in construction projects. There are a variety of ETs available in the market that are applicable to the construction industry; some are well known, some not. Some of these have been evolving since the 1990s whereas some are relatively new to the world. Generally, they are still in their infancy. The technologies that will be looked at in this paper are as follows: 3D printing (3DP), artificial intelligence (AI), augmented reality (AR) and mixed reality (MR), building information modelling (BIM), drones, mobile technology (MT), robotics and virtual prototyping (VP). A description of each of these ETs is provided below.

3DP, also known as additive manufacturing, has been presented to deliver innovative projects in the construction industry. It is a method of building that involves the sequential layering of materials, usually metallics, concrete or plastics, to create a geometric components or entire structures. It can also be used to create prototypes. 3DP only works when it is powered with a data source. Within construction projects, a common source is computer-aided design, which is used to create three-dimensional digital models. This model powers 3DP and allows the printer to read the instructions which create the output of the successive layers that are fused together to create the physical structure or model. The emergence of building information modelling can provide new ways to facilitate 3DP (Designing Buildings Wiki, 2020).

AI is the ability of a computer to perform tasks in a similar way that humans do, providing a similar level of intelligence to complete these tasks. This requires learning from historical data. To date, there are no AI systems available that can match human ability. AI uses two different types of approaches to gaining intelligence: a top-down and a bottom-up approach. The goal of the top-down approach is more symbolic, as it tries to replicate intelligence independently of the brain structure. The goal of the bottom-up approach is more about connections, which is to create artificial neural networks which imitate the brain structure. These approaches can be used to learn from historical construction data to identify efficiencies that can assist with decreasing time and cost (Encyclopaedia Britannica, 2020).

AR, which is an aspect of MR, offers a different way to experience construction projects. It is essentially a copied view of the real-world environment, whose elements are augmented or added with computer-generated inputs. It is often compared with virtual reality which replaces the real world with a simulation, whereas AR shows the real world but adds to it, providing you with a three-dimensional model of the design you are working with. AR software derives actual coordinates to provide an interactive experience. It also provides the ability to identify clashes in designs, which make it easier to make design choices or alterations. It is available for all types of projects, big or small, so even the smallest of projects can utilise the power of AR (Autodesk, Inc., 2020).

BIM is a process with a smart three-dimensional model as a foundation. It provides construction (and architecture and engineering) professionals with tools and insights to be more effective during the planning, executing, controlling, and managing of structures, including buildings and infrastructure. BIM in construction has gained momentum within the past five years. Much of the power in BIM is the ability to collaborate through each phase of the construction process. This smart process helps to identify clashes early on with the help of the entire team instead of just one segment. In short, it helps visualise two-dimensional plans. In large, it has the potential to transform the Architecture, Construction and Engineering industry by facilitating better communication and estimation, clash identification, risk and cost reduction and smoother handovers (Autodesk, Inc., 2020).

Drones, also known as unmanned aerial vehicles, are an ET that have a direct impact on construction teams. Drones collect data from above in real time, which can be particularly useful in site management for progress tracking purposes. This can help identify problems become they become bigger issues, and it is done by using GPS ground markers to calculate actual positioning. Additionally, drones are useful on construction projects in other areas, such as surveying, safety management, and providing measurements. For instance, real-time measurement of the volume of materials on site, such as soil, can be detected by drones. Overall, drones can help save resources and time on construction projects (DroneDeploy, 2020).

MT is available in construction projects as a collaborative software that is available for use in any geographical location. This is highlighted by the ability to send data from any location back to a central database. MT also highlights the ability for several users to communicate and collaborate via mobile devices simultaneously. Given the increasingly growing mobile workforce in construction, company executives have wanted to find ways to make teams more efficient. MT solutions create ways for teams to be more interactive, efficient, communicative, and collaborative, which assist in achieving project management goals. The biggest takeaway is the ability of MT to provide real-time project information to project managers who can make decisions faster as a result (eSUB, Inc., 2020).

Robotics are the essence of the automated world, bringing big opportunity to the construction industry. Robots can automate several types of roles typically done by labourers. Robots are particularly common in 3DP, facilitating the construction of buildings, homes and even bridges. Demolition robots can even make the process of crushing concrete and gathering debris (among other things) more efficient. Robotics in brick laying is also common these days, where entire houses can be brick-laid in just a few days. Robotics are one sure fire way for project managers to enable lean construction practices on projects, especially given the high-quality output of work that robots produce (Construction World, 2020).

VP is a computer aided design process that allows construction teams to enhance design communication without producing a material sample. This can be done throughout the following phases: project information collection, three-dimensional model building, and process simulation. This is done by integrating different design software at each stage, which allows for early detection of design issues. Teams can use VP to visualise and simulate sites at each phase, which can help with construction safety as well. This is done by detecting factors that are likely to cause an accident in advance so they can be prepared for or eliminated by re-working the design. Additionally, VP makes it easy to understand the life cycle information for buildings, which also benefits design (Aneesh & Vasudev, 2014).

The big question is this: do these ETs add actual value to construction projects, or is it merely perceived value? The ETs discussed here will be rigorously reviewed while collecting secondary data as part of the literature review. The aim is to uncover the ways these technologies impact the construction industry today and identify how they add perceived value construction projects. Then, primary data will be collected in the form of expert interviews. Those who are experts with these technologies within the context of the construction industry will be asked to be interviewed. The aim will be to understand if the perceived value reviewed in the literature review translates to actual value. The results will be shared, which will cover the opportunities and challenges these ETs bring to construction projects. Then, the overall findings will be discussed. By the end of this paper, you will have depth of information on each of these ETs and their impact on construction projects.

Table 1: Abbreviations used in this paper relating to emerging technology

Abbreviation	Full Phrase
3DP	3D Printing
AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modelling
ET	Emerging Technology
MR	Mixed Reality
MT	Mobile Technology
VP	Virtual Prototyping

2. Literature Review

To explore this theme, a thorough review of ET in construction projects has been completed. It was completed to help understand the impact that these technologies have on construction projects. Given the information that was collected, it made logical sense to group these impactful areas by project phase and knowledge area, as put forward by the Project Management Institute (PMI) in their 'A Guide to Project Management Body of Knowledge' (PMBOK® Guide Edition 6). The project phases, in chronological order, are as follows: initiation, planning, executing, controlling and closing/handover. The information is then categorised by project knowledge areas, which are as follows: integration, scope, schedule, cost, risk, quality, resource, communications, procurement, and stakeholder management (Project Management Institute, 2017). Note that not all these project phases or knowledge areas are reflected in the literature review, which ultimately depended on availability of relevant journal articles.

To curate the most relevant list of literature to review, parameters were put in place to ensure this was a quality review of available documents. This was done by choosing to review only journal articles, specifically those published within the last five years. This ensures the material reviewed is relevant. Also, Scimago Journal Rank database was used to identify the highest quality rankings. Only journals rated with a 'Q1' or 'Q2' ranking were used in this literature review. 'Q3' rankings and unranked journals were not considered for this paper (Scimago, 2020). With these parameters in place, a relevant and high-quality literature review can be prepared.

2.1. Project Initiating Phase

The Project Initiating Phase is defined as the formal recognition of the beginning of a project. This involves identifying stakeholders and developing a project charter (Project Management Institute, 2017). No ETs are reviewed in this section, as no literature was found showing ET is impactful in these areas. The ETs reviewed were found to be applicable in the remaining project phases.

2.2. Project Planning Phase

The Project Planning Phase is defined as creating and maintaining a workable plan to accomplish the purpose of the project. This involves developing a project management plan which encompasses all of the project knowledge areas (Project Management Institute, 2017). The ETs reviewed in this section are those that are impactful in the project planning phase.

2.2.1 Project Scope Management

The Project Scope Management knowledge area has been identified as an impactful area for ET within the planning phase. VP is a proven ET that assists with design management. Specifically, the designing of smart building envelopes. An experiment was done using various softwares, which resulted in understanding that VP can assist in various ways. This included the ability to use parametric techniques to generate related alternatives in the design by making subtle changes to the prototype model. They were also being able to assess physical impact of building envelope performance on a physical model, derived from the VP (Kim & Kim, 2017).

AR is another ET proven to assist with design management. This has been tested by using panoramic view of a refurbishment construction site and imposing BIM data onto this view. Then, users who were experienced in construction – and without previous experience with this type of technology – were able to successfully audit the design in a semi-AR experience. The quantitative results received by the moderator of the experiments showed a positive response to the semi-AR conditions (Gheisari et al., 2016).

Additionally, AR is also useful for moving away from two-dimensional paper plan documentation for decision making, to a more automated task system. The results of an experiment show that those using AR were able to complete tasks sixty percent faster, all while having to think less in the process, compared with those completing the same task using paper plan documentation. A challenge is that accuracy is significantly less in the AR experience, as it has much less detail than the paper plan documentation (Chalhoub & Ayer, 2019).

Moreover, in China, a review of the BIM process used by construction teams was undertaken, and most use cases were primarily applicable to design management. Three different types of BIM approaches were reviewed, including: integration, decentralization, and supplement. They make up a transition process which is very common amongst projects in China. It starts with a complete model, which is then transformed into three-dimensional models. The collaborative nature of BIM allows for multiple consultants (designers), contractors and project managers to access an up-to-date design simultaneously so that it can be effectively carried out (Li et al., 2018).

Lastly, drones are another impactful technology used in this knowledge area. They can impact scope by surveying land to identify site boundaries. This technology replaces the need for bulky tools and equipment that otherwise would be needed to carry out the task. This brings an opportunity for faster services at a lower cost. The impact of drones in construction is expected to increase moving forward (Li & Liu, 2019).

2.2.2 Project Schedule Management

The Project Schedule Management knowledge area has also been identified as an impactful area for ET within the planning phase. 3DP offers the opportunity reduce the amount of time spent on the project. Specifically, for 3DP metal structural components, total time was reduced by thirty-five percent to produce a conventional wall. The challenge is that, generally, the faster the build, the lower the fabrication quality. To date, this technology is far more common for off-site manufacturing to ensure high-quality production (Buchanan & Gardner, 2019).

2.2.3 Project Cost Management

The Project Cost Management knowledge area has also been identified as an impactful area for ET within the planning phase. In this case, BIM is proven to assist with the analysis of cash flows and choosing financing options based on a multiple design options. Traditionally, these were time-consuming processes which needed manual intervention, comparing schedules with cost plans. Because BIM allows for detailed levels (or dimensions) of project information in one integrated model, analysing cash flows can be mostly automated. Some aspects of payments needed to be manually entered due to contract-specific requirements not understood by the BIM system (Lu et al., 2016).

AI is another ET proven to assist with cost management. AI was used to train and test datasets from sixty-eight concrete bridge projects using a method called feed-forward artificial neural networks (FFANNs). Using these results, they were able to estimate a bill-of-quantities (BoQ) for a similar project using only a few variables available in the planning phase. It was found that using AI methods resulted in an improved level of accuracy in the resulting BoQ (Dimitriou et al., 2018).

Additionally, when contractors need to submit project bid prices for requests for tender (RFT) on bridge construction projects, they need to be accurate to ensure the contractor is in a good financial position if they win the bid. AI, when used to test models against data only available in the planning phase of the project, has been proven to accurate predict project award price. This, in turn, helps contractors estimate projects more accurately (Chou et al., 2015).

Lastly, 3DP, partly due to its impact on time reduction, offers the opportunity to save on project costs. This is due to the decrease in labour required because of increased automation of production. This also impacts a decrease in re-work, which would generally add to project costs (Buchanan & Gardner, 2019).

2.2.4 Project Risk Management

The Project Risk Management knowledge area has also been identified as an impactful area for ET within the planning phase. BIM can be used to provide project teams with an early-warning system for cost and schedule overruns. In this case, a protype was created – combining BIM with earned-value analysis – to help in this area using a real-life project as a model. However, it needs to be studied further during practical application (i.e.: an actual construction project in progress) to understand how well it provides risk management support (Sun et al., 2015).

2.2.5 Project Quality Management

The Project Quality Management knowledge area has also been identified as an impactful area for ET within the planning phase. AI, in this case, can be used to ensure structural steel adheres to guidelines put forth by Standards Australia and the Australian Building Codes Board for fire resistance and safety. This is done with use of Artificial Neural Networks and Genetic Algorithms – using a trained dataset – which provide improved results over general mathematics, providing more accuracy of the performance on steel structures against fire (Naser, 2018). Additionally, AI can be used to understand what will happen to different types of materials – such as concrete, masonry, steel, and timber – under extreme temperature conditions. This is critical to understand during the project planning phase (Nazer, 2019).

VP is another ET proven to assist with quality management, specifically with continuous process improvement. VP has been proven to assist to power a physical three-dimensional model of a city which can be created in seconds. This model can be tested against various city scenarios such as population, traffic, and temperature –

which can help measure quality standards of the model (and even compare new alternatives). The model does have limitations arounds size and shape type of buildings created in three dimensions. Thus, it needs further development (Fukuda et al., 2016).

2.2.6 Project Resource Management

The Project Resource Management knowledge area has also been identified as an impactful area for ET within the planning phase. BIM, in conjunction with computer based simulation software, can be used to effectively plan for the occupational health and safety (OHS) of labourers on construction sites, by simulating labour-based scenarios for emergency evacuation that could occur under various conditions during the project executing phase. These simulations can also be created to portray different construction methods. The result provided is the approximate total evacuation times for each floor for all labourers and highlights areas of congestion (Marzouk & Al Daour, 2018).

Additionally, BIM also supports OHS in other ways. Specifically, with four-dimensional BIM models (three-dimensional model plus scheduling data), it provides a visual understanding of the construction site prior to the project executing phase commencing. Thus, BIM can help plan for future potential hazards. The opportunities increase when combining BIM with other ETs, such as AR (Martinez-Aires et al., 2018).

2.2.7 Project Procurement Management

The Project Procurement Management knowledge area has also been identified as an impactful area for ET within the planning phase. It has been uncovered that BIM can help project teams create sustainable procurement practices, however, improvements would need to be made before that can occur. Changes need to be made to the assessment of sustainability criteria within the BIM system, and an innovative procurement system would need to be created to serve these changes. Overall, the opportunity is available, however a unified approach needed to be taken to see it through to fruition (Chong et al., 2017).

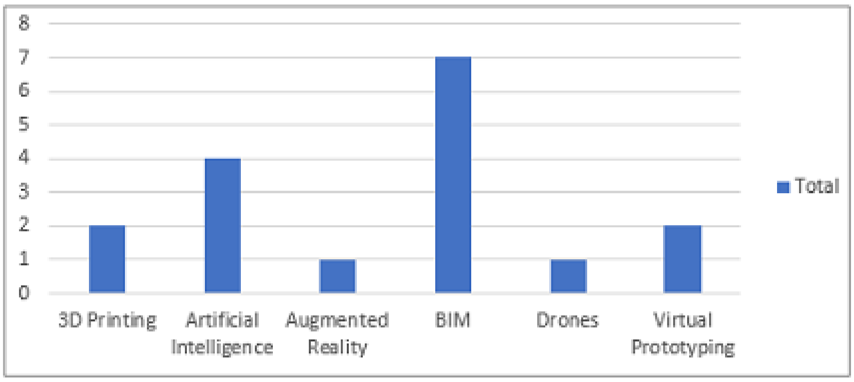

Figure 1: Cited ET journal articles which impact the Project Planning Phase

2.3 Project Executing Phase

The Project Executing Phase is defined as carrying out the project plan. This involves directing and managing project work, with a focus on quality, communications, risk, procurement and stakeholder engagement (Project Management Institute, 2017). The ETs reviewed in this section are those that are impactful in these areas.

2.3.1 Project Quality Management

The Project Quality Management knowledge area has also been identified as an impactful area for ET within the executing phase. MT offers a vast number of mobile applications (apps) available to construction teams, all of which have been developed to reduce process complexity. These apps impact the areas of safety, project management, cost management, site operations, computer aided design, BIM and estimating. When surveyed on mobile app benefits, top and middle construction managers in New Zealand highlighted benefits of overall improvement in productivity and profit margin for the project. Limited time to learn, difficulty to learn and cost prohibition were noted as reasons for barrier of mobile app adoption (Liu et al., 2019).

Additionally, a mobile BIM app was studied in the context of an airport construction project, highlighting the impact on continuous process improvement. In this case, BIM project information was delivered to workers via tablets in hopes to achieve lean construction principles through digital transformation. This was achieved by delivering BIM directly to the construction site, versus the office environment. Benefits are highlighted in the project controlling phase as well. However, there were challenges with implementation due to the size and complexity of the project (Koseoglu & Nurtan-Gunes, 2018).

Lastly, AR has also been studied on its positive effect in this phase, specifically with reducing process complexity. An experiment was conducted with sixty-one people – professionals, and students – who were asked to assemble a complex piping using AR technologies. It was found that, regardless of the type of person undertaking the task, the process saved timed compared with conventional methods. However, further experiments would need to be completed to understand the impact across the entire construction industry (Kwiatek et al., 2019).

2.3.2 Project Resource Management

The Project Resource Management knowledge area has also been identified as an impactful area for ET within the executing phase. Drones and related technologies are known for impacting the area of occupational health and safety (OHS) in construction. This is done through drone collecting and relaying real-time video to construction managers, for the purposes of site safety inspection. Drones were tasked with collecting data on whether workers were wearing hard hats or not, and the results were positive (Li & Liu, 2019).

Moreover, AR has been identified as useful in OHS scenarios, specifically hazard recognition and avoidance. By using a wearable device, the worker can receive information on dangerous situations without the need to analyse the data they receive in their device. There were positive results with the on-site hazard identification system, which uses an image capturing device to collect pictures of the construction site. This information is fed to the wearable device and notified the worker. However, there were also some issues. For instance, workers sometimes block other workers on the site images, which can provide skewed data (Kim et al., 2017).

AR has also been reviewed for its impact in other OHS areas, specifically in safety training, site safety inspection and instruction. Although there is good research presented to show that there are use cases for these impact areas, technology development still has a long way to come to create scenarios that mimic a human-based situation (Li et al., 2018).

AI has a different way of making an impact to OHS, specifically in tunnel boring, using a Tunnel Boring Machine (TBM). Given a TBM is very sensitive to geological changes, and given it is difficult for it to monitor both equipment status and rock mass in real time to make critical decisions, AI plays an important role in this area. This is done by using machine learning to mine big data collected by the TBM to create new models for predicting rock mass, along with using artificial neural networks to determine the quality of the rock mass. These innovations can help prevent disastrous occurrences that could result in real-time changes to the rock mass being bored, which in turn can potentially save lives (Li et al., 2019).

Additionally, VP has been proven successful in carrying out bridge maintenance projects. It eliminates the need for manual compatibility testing for fall protection supplementary devices (FPSD), which is generally done on a trial-and-error basis. VP identifies clashes confirms validity of FPSD systems before arriving on site, which eliminates issues such as safety risk exposure and productivity losses. In this case, VP provides opportunity for more efficient work, cost savings and fewer injuries (Zuluaga & Albert, 2018).

Lastly, MT also has an impact in OHS, specifically by predicting the movement of workers on site. In one case, workers wear mobile sensors which monitor body posture to identify when issues arise, such as body postures that result in work-related injuries. The goal of actively collecting and monitoring this data is to enhance safety by preventing work-related injuries (Nath et al., 2017). In another case, both workers and equipment were monitored on the construction site by predicting future movements to prevent collisions, thus, enhancing OHS. The results showed a high-level of accuracy (Zhu et al., 2016).

2.3.3 Project Communications Management

The Project Communications Management knowledge area has also been identified as an impactful area for ET within this phase. VP can be used as a part of the project management information system. In this case, the VP model can be used to provide documentation to the labourer. Using the model to create pictographic instructions, the labourer can work toward a prefigured goal, without verbal communication (instruction), all while minimising error, which without instructions, leads to inefficiencies and could create issues of delivering scope. However, improvements can be made on delivering the pictographic content to the labourer (Johnston et al., 2016).

2.3.4 Project Procurement Management

The Project Procurement Management knowledge area has also been identified as the final impactful area for ET within the executing phase. Drones are proven to assist with supply chain management on construction sites. They help manage this by transporting goods from one point on site to another. Once the supplies are dropped at the site, they are detected, identified, and tracked using GPS. Then, they are automatically moved to their appropriate location (Li & Liu, 2019). Additionally, MT is used in supply chain management as well. In this case, mobile internet has been researched as an ET that can assist in filling the gaps needed to provide real-time, up-to-date information on the construction supply chain. The mobile internet, in this example, is a collection of connected devices with internet capability that are all connected to one system for complete visibility. However, security issues do exist and would need to be managed appropriately (Shi et al., 2016).

3DP is also proven to be impactful in this area, specifically with materials supplies. In this case, a particle-bed is needed as a base on the ground prior as a first step in the concrete construction process. Using 3DP technology, particles of different size, material and overall design can be created for different scenarios, which creates new opportunity for structural design and construction (Lowke et al., 2018). Printing cementitious materials provides advantages of being cost effective, flexible in design, high-efficiency and environmentally friendly. Labour reduction would be a side effect of implementing this technology (GuoWei et al., 2018). Similarly, this technology has also been used to construct walls. A foam formwork wall is 3D-printed around a concrete wall, encasing it with thermal properties. The technology has been tested to work in fifty-centimetre increments (Furet et al., 2019). 3DP structures that require steel reinforcement prove to provide further challenges. This is because these structures would require hollow voids to insert the steel bars manually. This, in turn, limits the architectural design freedom (Tay et al., 2017).

Robotics have also been shown to play important role in procurement of construction projects during the executing phase. Such examples as robots automatically coating and painting the entire façade of a high-rise building and the industrial personalisation of buildings that are created on an assembly line are just the beginning of this type of technology entering the construction industry. Where the application makes sense, establishing robotic factories directly only site for prefabrication purposes is a logical step forward for the industry (Bock, 2015). The automation of works such as bricklaying, where a robotic system can lay one thousand bricks per hour, and glazing machines, where the robots installs glass panels and windows more than one thousand kilograms, are also on the market now. Robotic 3DP has also been happening for years; however, it is still a novel concept in the industry. However, single-storey, detached homes have been 3D-printed with concrete since 2003 in China (Bogue, 2018).

Additionally, robots are enhancing construction techniques by providing the ability to automatically assemble parts of a modular structure by providing specific markers on site (Feng et al., 2015). Robots can also undertake the construction of walls and even high-rise buildings. For wall construction, a scaffolding rail system is set up on site, and a mobile robot is attached to it, moving along the scaffolding while it injects concrete to create a composite wall (Więckowski, 2017). For high-rise building construction, a robotic assembly system (RAS) has been developed, which involves three sub-systems – a robotic bolting device, a control system, and a robotic transport system. These sub-systems together help perform tasks such as steel beam erection, placement, alignment and bolting in place (Casi et al., 2019).

Cable-driven robots are known in the industry for their ability to move hazardous materials throughout construction sites, which benefits supply chain management. In this case, they are also able to construct architectural systems, such as a three-dimensional model. The use a claw to drop material in place to build the model, which it does so based on a computer model (i.e. created in computer-aided design). It provides collision-free path planning in which they can identify obstacles and the interaction of the cables use to ensure this happens without error (Pinto et al., 2017).

Moreover, these high-tech developments in robotics do offer their share of adoption challenges in the procurement area. Contractor-side challenges include these technologies being too risky to implement. Client-side challenges include lack of effectiveness and disruption to teams. Work culture challenges including issues regarding human-robot interaction. Regarding cost benefit, there are no significant cost-benefit studies that show labour cost or time saved, among many other variables that should be considered (Delgado et al., 2019).

Drones, like robotics, can make an impact in this area as well. Drones weighing just twelve kilograms can lift concrete blocks, and lay them down in place, with no human interaction, using a laser-based positioning system. This technology shows promise of building walls without the use of scaffolding, however further research is required to learn more about similar, more advanced applications (Goessens et al., 2018).

Lastly, AI is known to assist with contract management in construction, particularly with managing disputes. Using historical data as a study, AI was used to understand the data and predict conflicts. The results were successful; results show that AI can be successful in data mining historical projects to locate related projects and understand what types of conflicts may arise. This information will better prepare contract managers in project execution, as they can prepare their expectations accordingly, minimising risk (Chou et al., 2016).

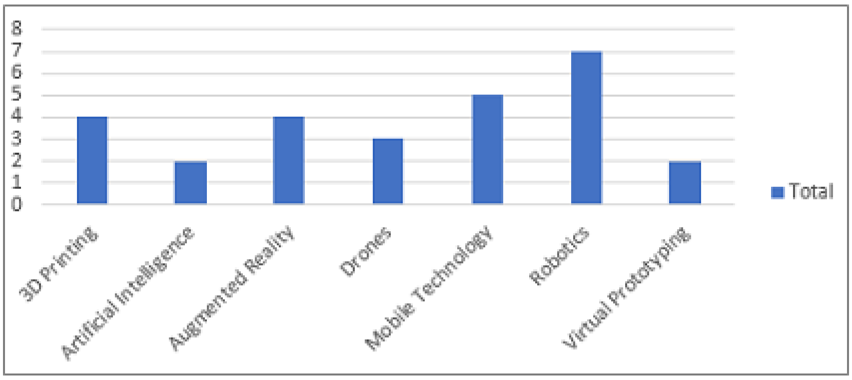

Figure 2: Cited ET journal articles which impact the Project Executing Phase

2.4 Project Controlling Phase

The Project Controlling Phase is defined as monitoring progress and taking corrective action when necessary. This involves monitoring and controlling project work while managing change, with a focus on scope, schedule, quality, resources, monitoring communications, risks and stakeholder engagement, and controlling procurements (Project Management Institute, 2017). The ETs reviewed in this section are those that are impactful in these areas.

2.4.1 Project Schedule Management

The Project Schedule Management knowledge area has also been identified as an impactful area for ET within the controlling phase. AR is known to provide a sense of realism to projects. In this case, an intuitive experience is created where four-dimensional scheduling information is attached to AR objects and displayed for the user. This helps with the controlling of schedule, all in a real-life type of simulation. This can be particularly helpful for long-distance managers who need to be updated on timelines. This is an improvement on completing the same type of tasks through physical field work (Kim et al., 2018).

2.4.2 Project Quality Management

The Project Quality Management knowledge area has also been identified as an impactful area for ET within the controlling phase. AR has been researched and identified as impactful for site and building inspections through an interactive, intuitive approach. Data can be captured instantly, which will ultimately reduce response time for resolving inspection matters that require immediate action to be taken. This is possible due to an integration between BIM and the AR platforms. However, it is still unknown the productivity gains that can be gained from this type of system (Machado & Vilela, 2020).

Additionally, AR can be used by site inspectors for the inspections of tunnel construction projects. Tunnel segment displacement is a key area that is tracked during inspections, and this method can provide specifics as to actual displacement versus designed displacement. This is done by creating a baseline virtual model of the tunnel which meets quality standards. The virtual model is actively compared with the real view of the tunnel. Discrepancies are identified in real time, creating cost efficiencies along the way (Zhou et al., 2017).

Robotics is another type of ET that impacts quality control, specifically in the inspection of structures. Given the time and resource intensive nature of building inspections, robotics offers efficiencies in these areas. Inspecting hard to reach areas to detect faults is a primary use case, given a high level of accuracy is required with this task (Almadhoun et al., 2016).

Continuing with the trend of inspections for quality control, MT provides an impact in this area as well. In this case, a system called HeadLight is used in public transportation in the United States to gather interview and field measurement data. It was found that the project inspectors using this technology experienced a twenty-five percent productivity gain by means of data volume, completeness, and variety, as well as overall time savings. A more complete picture of data was shared, and reports were submitted in a timely manner (Yamaura & Muench, 2018).

Lastly, drones also make an impact when it comes to quality control, this time the focus is on bridge inspection. Drones were sought out as a more cost-effective, efficient means of bridge inspection because of an increase in the amount of bridges that are starting to deteriorate worldwide. Drones can identify many types of damage on a variety of types of bridge materials (Seo et al., 2018). It is important however to make sure you do not get “visual overload” by means of too many photos and videos taken by your drone. This is a major issue in the visual monitoring of construction projects. A new methodology has been created to combat this issue, where a high accuracy of photo and video selection is provided to teams (Ham & Kamari, 2019).

2.4.3 Project Communications Management

Lastly, the Project Communications Management knowledge area has also been identified as an impactful area for ET within the controlling phase. In this case, mobile AR aids in progress reporting. The application uses BIM as a foundation to gain a real-life view of the project in real-time. Then, teams can control the project and provide real-time updates on actual versus planned progress using AR on-site in real-time. Overall, this system provides a more effective way to control projects (Zaher et al., 2018).

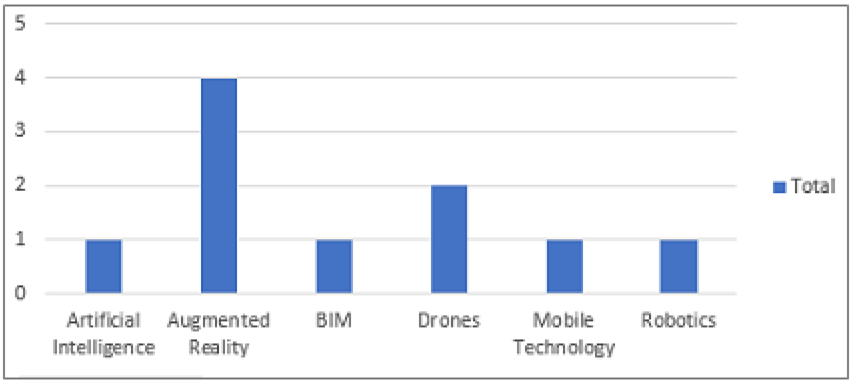

Figure 3: Cited ET journal articles which impact the Project Controlling Phase

2.5 Project Closing (and Handover) Phase

The Project Closing Phase is defined as bringing the project and paperwork to one hundred percent completion and entering the history in a database (Project Management Institute, 2017). Once this occurs, a handover will happen to the operations management team. The ETs reviewed in this section are impactful in these areas.

2.5.1 Project Communications Management

The Project Communications Management knowledge area has also been identified as an impactful area for ET within the closing and handover phase. BIM has been tested to enhance facilities management by providing documentation control and sharing information from previous project phases into the maintenance and operations phase. This is particularly useful for large scale projects in the mechanical, electrical, and plumbing applications. These applications are visualised not only for the construction team but for the operations team moving forward into the building's life cycle (Hu et al., 2016).

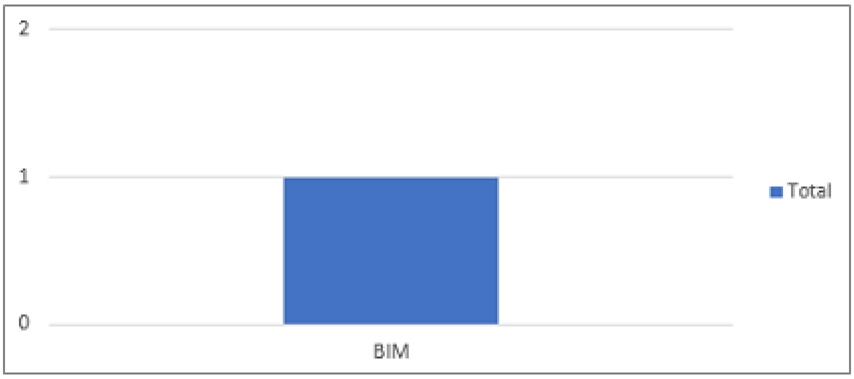

Figure 4: Cited ET journal article which impacts the Project Closing (and Handover) Phase

Considering all the information that is available on ET opportunities, it is interesting that the one piece of information still unknown is this: do ETs add actual value to construction projects? Given all the opportunities and challenges presented, this question needs to be answered from a subjective point of view, by experts in each ET area. The opportunities presented in this review seem to outweigh the challenges. However, the challenges presented may outweigh the opportunities if, for instance, cost is too high or if quality levels cannot be reached for a high-quality project. This will be answered by the seven expert interviewees.

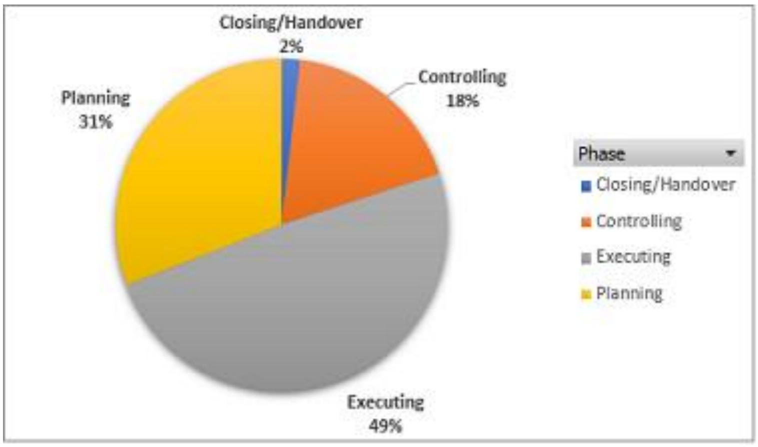

Figure 5: Cited ET journal articles categorised by Project Phase

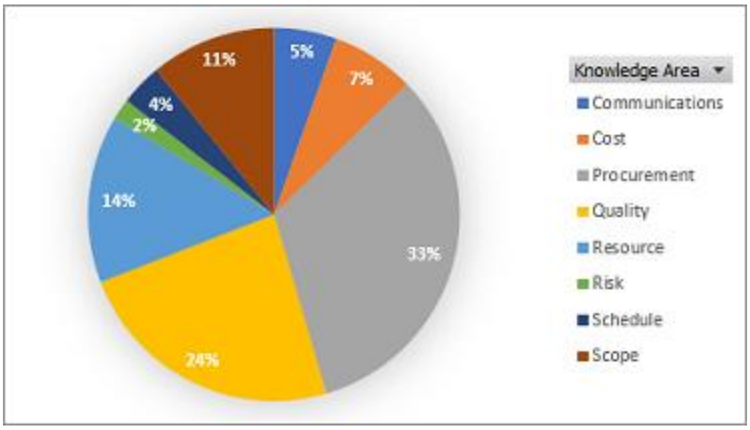

Figure 6: Cited ET journal articles categorised by Project Knowledge Area

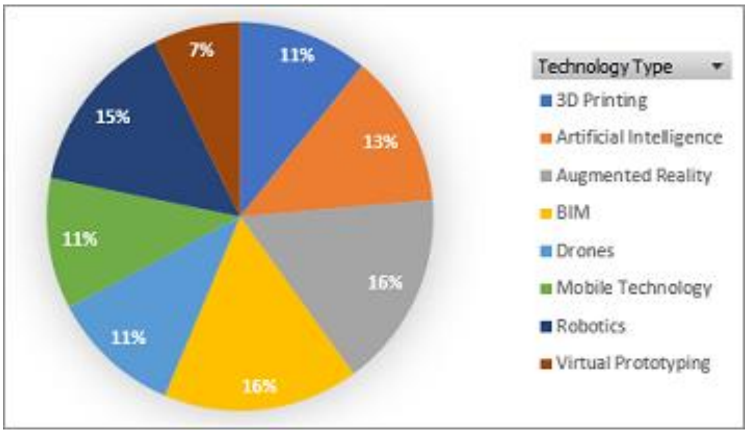

Figure 7: Cited journal articles categorised by ET type

3. Method

To gather primary data, an appropriate method was identified to ensure the approach would result in the best data for the research paper. The following aspects of the method will be reviewed: participants/sample, materials/measure, design, procedure, and analysis. Each of these aspects are important to understand, the study would require each of these aspects to be replicated to ensure similar outcomes are found.

The first aspect of the method was participants/sample. There was a total of seven participants in the primary research study. These participants were recruited because they were high-level people in companies that facilitate the use of ET in construction, which was relevant to this research. They were recruited my means of email, which required research and preparation of messaging (this will be covered further in this section when discussing procedure). Of all the potential interviewees, nine said yes, one said no, and fifteen did not respond to the request. The reward for participation is that interviewees would be able to receive the final research paper including their results from the study. All interviewees requested to take part in this study were from Australia, with the exceptions of two people: one person from Hong Kong and one person from the United States.

The second aspect of the method were materials and measure. To prepare for the expert interviews, a list of interview questions was developed. In total, seven questions made up the list. The questions were specific to the ET that the expert interviewee had experience with within the construction context. The categories of questions asked were involving the following: their experience with the technology, the impact of the technology, opportunities created by the technology, challenges presented by the technology, adoption of the technology, productivity impact, and other aspects that we had not previously covered (for a complete list of the interview questions, please see Appendix B). Equipment was required to carry out the primary data collection. A personal computer and internet access were required, along with email and calendar functionality, to communicate with interviewees and schedule interviews at mutually available times. Microsoft Teams was required to host (and in one case, record) interviews. Professional networking website LinkedIn was required to find potential interviewees. An application, Clearbit, was required to find potential interviewees' email addresses for targeting. An additional application, Otter.ai, was used to transcribe the interviews once completed. And lastly, a personal Sony ICDPX470 Digital Voice Recorder was required to record interviews so that they can be appropriately filed with Bond University at the conclusion of the research project.

The third aspect of the method was the design. This study was designed to perform qualitative research. The stance that was taken in this methodology was that each interviewee should have had the same experience, even though they each were expert in a different area of ET in construction. What this means was that the interview questions were designed in a way that the questions were the same for each interviewee. The only thing different was the context. For example, a generic template for these questions were initially designed with '[insert technology type]'. Then, finalised, targeted questions were created by inserting the technology type. The finalised, targeted questions were the ones that were sent to interviewees in advance of the interview and asked during the interview itself. By taking this methodical approach, it ensured the results would all be comparable, despite the technologies being different. This design aspect is important because it ensures there will be a quality discussion.

The fourth aspect of the method was the procedure. This aspect is important as it provides a step by step account of what occurred throughout each step of the primary data study process. There were six phases to this process, as follows: researching potential participants, informing potential participants of the study, receiving replies and responding to potential participants, scheduling interviews, hosting interviews and following up. Each of these phases were critical in gathering primary data for this study.

The first phase in procedure was researching potential participants. To find the appropriate participants, web research was undertaken to identify the companies that utilise the ETs discussed in this research project. Next, a free trial of Sales Navigator, which is an offering from professional networking website LinkedIn, was used find those target companies and identify the high-level decision makers within each company. Next, an application called ClearBit was utilised to find the decision makers' email addresses at their companies. A spreadsheet was made in Microsoft Excel to organise all the targets of potential interviewees, which leads us into the second phase of the procedure.

The second phase in procedure was informing potential participants of this research study. The goal was to reach out to potential interviewees via their company email in hopes of receiving a fast response, specifically given the relevance of the study with their line of work. First, a templated email message was crafted which could be sent to any target, as it is including '[insert technology type here]' at certain points. Utilising the completed spreadsheet created in the first phase, individual email messages were crafted using the email addresses found along with the templated email message. That templated email message was then made specific for that potential interviewee's area of technology specialty. Then, the email was sent out. This process was completed for twenty-five potential interviewees. Emails were all sent in the morning early in the week in hopes of receiving the highest reply rate.

The third phase in procedure was receiving replies and responding to potential interviewees. Over the course of three days following the completion of the second phase, enough responses were received to fulfill the needs of the study. There was a variety in terms of technology types that the potential interviewees, which sufficed the needs of the study. All replies were pleasant, and all were willing to move forward with the interview, except for one person who said yes, however his Human Resources team asked him to deny the request after the fact. If a potential interviewee responded with yes to the request, then the fourth phase was carried out accordingly. In the one case where it was ultimately a no to the interview request, a response was sent thanking them for their time and offering to send the final research results once completed.

The fourth phase in procedure was scheduling interviews. It was at this point that potential interviewees are now referred to as interviewees. Scheduling interviews was completed by using Microsoft Outlook in conjunction with the Microsoft Teams application, as when a meeting (interview) request is created, there is an option to include a virtual Microsoft Teams meeting. A message was crafted for each interview thanking them for their participation, along with a virtual meeting request, a list of the interview questions that will be asked during the interview, an explanatory statement for the research study, and a participant consent form which was requested to be submitted back with their completed information on it. This process was done the same for each of the interviewees who accepted to take part in the interview, ensuring conformity.

The fifth phase in procedure was hosting interviews. This happened between the dates of the 2nd July 2020 and 16th July 2020. As mentioned, these interviews were virtually hosted using Microsoft Teams. This was primarily due to the COVID-19 situation where social distancing practices were the norm at the time. It also creates a level of convenience due to each party's busy work and University schedules. The interviews were kept to the thirty-minute time allotted, except for the case of two interviews which, at the request of the interviewees, lasted nearly one hour each.

The sixth and final phase in procedure was follow up. This was required for three reasons. Firstly, a thank you email was sent to each of the interviewees immediately following the interview thanking them for time and willingness to participate. Next, in the cases where the interviewees had not yet returned the completed consent form, an ask was made from them in the follow-up email as well. And lastly, each of the interviewees were sent the final research results upon completion of the research project.

The fifth and final aspect of the method was the analysis. Given this is a qualitative study, an analysis was completed after receiving and recording the results. To find more information about this analysis, please review the discussion in section five.

4. Results

During this project's Executing Phase, expert interviews were conducted with experts in various areas of ET that apply to construction projects. One expert interview was not specific for construction, however general to innovation and technology. Interviewees were numbered to keep results organised, all while keeping their identity anonymous, and the word 'they' will be used instead of 'he' or 'she' when referring to them.

Expert Interviewee One leads construction education training at a leading construction technology company in the United States, specialising in mobile technology. They spent four years in this company, with ten years spent working for a head contractor prior to engaging in this current role. Expert Interviewee Two is an operations manager at a leading digital engineering and BIM firm with operations across Australia. They started using Revit software in 2004 and have been with the current company for four years. Expert Interviewee Three is a professor and a achieved their doctorate at a leading University in Hong Kong. They completed their doctorate between 2000 to 2005 and five in construction virtual prototyping. Expert Interviewee Four is the chief pilot for a leading drone company in Australia who also manages operations and training. They have a background in aviation (including hours of flight time) which was achieved prior to joining their current company, which they have been at for nearly four years. Expert Interviewee Five is the chief technical officer of a leading robotics company in Australia. They have been involved in computer-controlled machinery since 1992 and been a part of their current company for fifteen years. Expert Interviewee Six is the founder and director of a leading mixed reality company in Australia. Having been working in the field since 2006, they pursued further education and are currently lecturing in the field. They have been at their current company for eight years. Expert Interviewee Seven is a professor of project management in Australia and previously an IT project manager for a major hospital project in the Middle East. Change innovation with technology is a highlight of their experience.

4.1 Mobile Technology

Expert Interviewee One spoke about the impact of MT in construction projects. MT impacts the construction industry and projects by creating an unprecedented level of connectivity. Communication is at a higher velocity, and teams can work on more on complex projects that are expedited and scrutinised more than ever. MT makes this possible while allowing plans and models to be made available to all members of the construction team through each project phase – in real time. This aspect may be what makes MT so exciting; the days of going back to the office to review project plans or to better understand a required variation are no more.

The biggest opportunity offered by MT is the ability to power a distributed workforce that can stay connected even through the most challenging of times. For instance, Expert Interviewee One cited many clients who are using MT to stay connected on projects throughout the COVID-19 crisis. Another opportunity is that MT is easy to adopt. This makes it easy for construction teams to stay connected throughout the entire project lifecycle, from pre-construction to operations and maintenance. Most importantly, this technology allows teams to take action. With most of us with phones at our fingertips, it is easy to use our devices to stay up to date with the project and take action if needed. MT provides the ability to track time, people, and materials as well, using geolocation. This is especially true given the upcoming wireless innovation with fifth-generation technology. And lastly, reporting becomes more streamlined as well. For instance, a construction manager can get automatic reports with tracking information, plan changes, site inspection details, and many other aspects of the project automatically.

These opportunities can only be realised once the technology is adopted. Firstly, not everyone on construction teams are mobile centric. Although MT offers productivity in your pocket, it needs to be used to realise the valuable outcomes. For instance, much of the construction workforce are older and did not grow up with a cell phone in their pocket. For them, it takes more learning, training, and managing to get these types of people on board with a MT approach. As for the younger people in the workforce, it may come easier to them, where less managing is required as they are already familiar with this type of technology.

4.2 BIM

Expert Interviewee Two spoke about the impact of BIM in construction projects. The first big takeaway from the conversation is that BIM is not merely a technology, it is a technology process, which is also known as digital engineering. BIM can make a big impact on companies who are not yet aware of what BIM can offer. For instance, contractors or subcontractors who are tendering on projects can get exposed to BIM during the tendering process. The information capture during the BIM process can be to the extent of what information is needed to complete the project once on site. BIM truly plays a big role in larger, more complex projects. This is because the BIM process can be quite expensive when capturing each element of construction. This process is worth it for the more complex projects, as BIM allows teams to identify clashes early on, far in advance of construction, with time to adjust the design.

The biggest opportunity offered by the BIM process is creating one source of truth for the entire project. This again is especially important for the larger, more complex projects, where there is a contractor, subcontractors, project managers, and many consultants are involved from the concept and design stages to project completion and operations. BIM ensures each party understands their piece to the overall project without the worry that something has changed as updates to BIM happen in real time. For larger projects, the BIM process is cost effective as a way on managing the project from beginning to end. The centralisation of project documents in one place is worth undertaking the BIM process just to make sure all parties can collaborate effectively. In one instance, with a mining project, visualisations provided by BIM helped get the project done earlier, saving fifty million dollars per day.

The biggest challenge with BIM is getting project teams to adopt the technology. For instance, with smaller projects using less parties to complete it, BIM may be cost prohibitive. Even so, “business as usual” may work for smaller construction teams. As time goes on, teams will get more exposure to BIM as it becomes more popular in construction projects. This may happen through government mandates, which make industry workers upskill. Or it may happen as companies work on larger, complex projects where BIM is chosen as the source of truth for the project. Open collaboration is the big goal with BIM and will eventually be understood as the reason why teams should choose BIM to carry out their projects.

4.3 Virtual Prototyping

Expert Interviewee Three spoke about the impact of VP in construction projects. VP can make a big impact in planning, especially the complex projects. VP helps contractors to build the building before construction commences. This helps save time because the building can be logistically planned out in advance, which enhances safety because hazardous situations can be planned for and simulated. VP provides greater detail than you would receive from BIM. It includes the construction methodology within the prototype, such as equipment required to complete the job. So, if scaffolding is required, it would be shown – along with potential clashes and safety hazards. This view into the future brings BIM technology to the next level and allows contractors and alike to prepare in advance for especially complex projects. Where BIM is limited to highlighting clash detection, VP provides a detailed overview of construction works and essentially shows a contractor how to construct the building. Overall, productivity is improved using VP because of its ability to promote communication and collaboration amongst project stakeholders, especially the contractors.

VP offers an approach which saves time by highlighting dangerous situations far in advance of when they would occur and by identifying construction issues. This is especially an opportunity for precast technologies. However, the opportunities provided do not come easily. They are cost prohibited for many projects that are smaller or less costly. These types of projects do not have the budget needed to undertake VP. Large, complex projects that require substantial planning and have large budgets are great targets for VP. It is important to note that not everything needs to be simulated using VP, only the critical construction activities. The biggest challenge to adopting VP technology is to get the BIM consultants on board with the process. If they are not on board, it will be hard for VP to succeed, as it is reliant on BIM to proceed. It is important to note that BIM includes schedule data which is the primary reason VP is reliant on BIM, as it already contains much valuable information about the project.

4.4 Drones

Expert Interviewee Four spoke about the impact of drones on site in construction projects. Drones present the opportunity to provide a big impact to the construction industry. Construction projects that involve data collection, land surveying, big roads, and earthworks have been proven to be positively impacted by drone technology. Data collection provides the biggest impact for construction projects, because drones have the ability to provide inspection photos from various heights, create three-dimensional models by taking a suite of photos from various perspectives, create three-dimensional models using laser scanning, and for select projects, even collect water samples for testing. Some drone applications available on the market even offer the ability to transport materials from one location on site to another location.

Drones offer big opportunities in the aforementioned areas. First, using laser scanning, drones can create a digital twin of a structure. This can be particularly useful in tunnel projects or in situations where safety is a concern, as no one is put in harm's way when the drone is making its scan. It is also efficient given its accuracy and ability to complete the task only using one person at the controls. Next, drones can calculate how much earth has been removed during an earthworks project. This makes for an efficient estimation tool. Additionally, drones can essentially replace the job of a traditional land surveyor, all by capturing data automatically and eliminating the need to use trigonometry and triangulation. Lastly, drones can help track progress of large civil construction projects, such as highways. Overall, the central theme here is increased safety, time and cost efficiency, and high-quality output. These efficiencies are seen best on large scale projects and makes work easier for labourers.

To realise these potential opportunities, drones first need to be adopted by construction teams. Although change management is a barrier for many teams, the adoption of drones is increasing exponentially. In addition to getting the greater construction team on board, there are cost and regulatory challenges to adopting drones as a tool for construction projects. The cost challenge is present given the technology is still emerging. The regulatory challenges arise because there are laws that need to be adhered to, which can get in the way of using drones. Once adopted, drones can help with site security, detect air quality, inspect bridges, complete non-destructive testing, and even complete maintenance such as window washing.

4.5 Robotics

Expert Interviewee Five spoke about the impact of robotics in both site and factory environments. In the factory, robotics is used to mass produce materials and modules. There are small, portable robots which are autonomously guided vehicles that work in the factory, and there is one type of big robot available in the market that works on big construction sites. Overall, when speaking about construction, robotics is still in its infancy stage.

When it comes to opportunities, robotics can lead to a decrease in labour/manpower, improvement in accuracy and speed, and generally frees up logistics that can be used in other areas of the project. Overall, the big opportunity that robotics offers a construction or prefabrication manager is increased value by means of decreasing time and cost while increasing quality. Those opportunities can be broken down into productivity gains. For instance, robotics offers increased safety given they are autonomous. The accuracy of robots is high which positively impacts the quality of the finished product. Speed is increased with this technology which cuts down the time spent on completing construction projects. And lastly, waste is reduced by using one-hundred percent digital plans to create a desired outcome. This expert interviewee’s area of robotics is in bricklaying, so in this case, the number of bricks and half bricks can be planned down to a single brick.

To realise this potential opportunity, this ET first needs to be adopted. The robotics industry is still relatively new, so adoption levels are still low. There are not many products on the market yet. However, the robotics offerings that are on the market are paving the way for future offerings, which could be used in the construction industry. A big challenge in implementing robotics and the biggest takeaway from this interview is that the robotics generally requires one-hundred percent digitalisation of plans prior to executing in a factory or on-site. The use of BIM is a foundation for robotics, so if anyone in the construction industry is considering using robotics to as an opportunity to increase efficiency and productivity, they will need to evaluate their plan for digitalisation of their project. If they are not already using BIM, they would need to adopt that first, so that the robot can understand what to do and how to do it. Then, it is up to the robotics software to complete the task.

4.6 Mixed and Augmented Reality

Expert Interviewee Six spoke about the impact of MR and AR technology on construction projects. The first takeaway is learning about the reality-virtuality continuum. From left to right you have, reality, augmented reality, augmented virtuality, and virtuality. The mixed reality space is all that is in between reality and virtuality. Many types of realities exist in the mixed reality space. So, when someone speaks about AR, it is not its own thing. It is part of a greater continuum.

The opportunity of MR truly lies in the ability to create an engagement model that accurately represents the model of that project. This engagement model can be used for marketing purposes, such as selling or leasing units or floors. It can be used to help executives understand what decision or change needs to be made in the project without overwhelming them with technical data. Essentially, the engagement model is a tool or conduit used to solve problems. For example, preparing for safety is one aspect that can be costly or not done well at all. The engagement model provides the ability for builders to do safety inductions in a virtual reality experience. One example shared is creating an engagement model of a project involving a tunnel boring machine. Labourers can experience an exact replica of that setting, inside of a tunnel and even experience what it would be like to experience certain catastrophes that may happen while in that setting, so they can prepare for these types of situations in advance..

This is all made possible by creating a digital twin, which is a complete digital version of that structure. This data is already available in projects that are using BIM. This same data used in BIM is already available, however it is used in a different way when speaking about the engagement model. It is less technical and, as it says in the name, more engaging. However, the one major challenge for MR applications is funding. This is ironic though, given that projects using BIM already have their information. It is just presented in a more technical way versus the engagement model. Bottom line is this: you do not invest in MR and AR. You use existing data to create a virtual environment that is linked in perpetuity to the life of the building, which collects all the important information in one place.

4.7 Innovation

Expert Interviewee Seven spoke about change and innovation with respect to general technology. Technology is generally oversold and underdelivered, which can come with a hefty price tag and a high failure rate. This has a lot to do with the implementation of the technology. That said, there is a lot of opportunity that technology can bring to projects. For instance, the automation of computers, also known as AI, will optimise scheduling needs for all types of projects. Routine tasks that are usually completed by project team members, such as project controls, can be fully automated. This automation gives project team members more time for design, storytelling, and people time – all which are important in the context of projects.

Even though technology implementation can slow us down as first, the more we implement new technology, the more we use it, we will find that it will make us more productive. There is essentially a learning curve that needs to be overcome. Expert Interviewee Seven cited computer printing technology as an example. When first implemented, printing was revolutionary. However, now, when analysed, they mentioned it takes eleven mouse clicks to print a PDF document. This innovation is not as revolutionary as it once was, however, computer printing is at a point where its productivity can be increased. It just took the learning curve of understanding new technology, using it, and now analysing it to get to this stage.

Adoption of technology can come with a price. Not all people are quick to adopt new technology, and not all implementations are done well, leaving teams with a lack of adoption. One aspect that may change this environment is gamification. Gamification is essentially the idea of adding game type elements to project management processes to help increase adoption. It does so by adding rewards for good behaviour, such as completing a task on time and accurately. It is all about changing the behaviour of team members to get them to use new technology to progress the project forward. Things such as leader boards and digital badges help promote good behaviour, making it a game between colleagues. Items such as sensors will help with the monitoring of goals, which help understand efficiency levels of tasks completed. One primary challenge of technology implementation is middleware. When those sensors, drones or other connected devices send data to another system, middleware is required to convert that data correctly. This is one area that can be particularly challenging with new technology.

5. Discussion

There are many ways that ETs such as MT, BIM, VP, drones, robotics, and MR/AR impact construction projects. This is seen through a review of recent literature, as well as through interviewing experts who have immense experience with each of these technologies. However, understanding the connection between the technological impact and project value is the true goal of this research paper. Several key factors to understanding this connection were found. The first is that BIM is the underlying foundation that enables most of these technologies to function. The second is that the cost to adopt ETs is not within existing budgets. The third is that ET is still in its infancy, which bars adoption. The fourth is that large, complex projects seem to be the project where ET is adopted. The fifth is that some of these technologies can provide environmental impact. Each of these preceding factors will be broken down into both barrier and access to value. Lastly, a review of what can be completed in future studies is provided for any researcher who is interested in this field and wants to advance studies further. Overall, the findings are interesting and allow us to think about which study may come next.

5.1 BIM is a Foundation

One key factor and finding in this research involves BIM. BIM is a well-known ET in part because it is a hot topic in the construction industry, where it is being used some of the most complex projects in recent years. It is known as the “source of truth” in projects where various stakeholders can access BIM and understand what exactly is required of them per plans – without having to consult with anyone else. It is exceptional in the way where data and visuals are combined for the entirety or the project. The data is captured in a way that is visually appealing and helps contractors or consultants complete their tasks easier – including communication on potential clashes or other issues.

BIM is not just the “source of truth” for the project information itself. It is playing this same role for several ETs that are presented on a project. For instance, BIM has been found to be the foundation for VP, MR/AR, 3DP, and robotics. It can be part of the foundation for MT, too. For VP, simulations are created to help contractors and other project team members understand what the final product will look like far in advance of construction. This is an outcome that cannot be provided without foundational data. That foundational data is BIM. It powers the virtual prototype, and without BIM, the process of gathering building model data would need to be undertaken. Therefore, VP is more common for larger, complex projects, because BIM is already in place and there is a greater need for simulation for understanding complex finishes and for safety outcomes. For MR/AR, an engagement model is created using the BIM data as well. However, it takes the data and creates visuals that are more meaningful. It does this by immersing you in the space. For robotics, take an example such as bricklaying. The robot can only complete the task if there are instructions on how to proceed. In this case, BIM provides the instructions on what needs to get completed. It is then up to the robotic software to show the robot how to complete those tasks. With MT, BIM can be introduced as part of the offering in which teams can access BIM from their mobile devices. However, that is just an option. Two-dimensional plans can be easily made available as well if BIM is not carried out on that project.

BIM is a powerful tool that can dictate which ETs can be used in a project, because it is the foundation upon with many ETs work. For example, if a project team not using BIM wanted to enable robots to lay bricks for single storey home, there would be two options: a) do not employ robotics on this project or b) invest in BIM so we can employ robotics on this project. Many times, the former would be chosen, mainly because of cost constraints. This will be covered further in the next section.

5.2 Cost of Adoption

When speaking to adoption of ETs, much of what was brought up during the literature review and expert interviews was the issue of cost. Many scenarios have a project team early in the project with a specific budget that is already planned out, leaving no room for additional technologies – even if these technologies are touted to add value to the project. What is found is that teams will choose one of the following: a) choose not to use ET due to cost limitations, or b) extend the budget to afford the ET.

That decision can be swayed because of recent projects that have successfully deployed ET. However, the problem still lies with the core issue, which is that ETs are not included in project budgets. This could be because these technologies are still in their infancy and/or because there are not enough use cases publicized to prove that they are (or are not) adding value to projects. That said, it is not fair to judge ET on its value by looking only at adoption. It is only fair to judge projects that have adopted specific ET(s) and judge them on selected criteria. Additionally, smaller projects have smaller budgets, so to try and make room for costly ET is not always made a priority. Sometimes it is just not feasible. The cost of adoption may be the biggest reason why ET is still in its infancy – because there are not enough use cases made public to help share the story from either side. This will be covered in the next section.

5.3 Infancy of Emerging Technology

Since the 1960s, with the inception of two-dimensional computer aided design, the use of ETs in construction have been on the rise. However, in those sixty years or so, not a lot has changed in construction projects. In fact, the construction industry is in a position where the productivity curve has flattened, and conventional technology is no longer increasing productivity in construction projects. In fact, the data shows that the industry is just as productive building structures in the 1960s in comparison to now. Given all the ETs available, this data is a bit shocking.

This data seems to be the result of lack of adoption. For instance, for VP, MR/AR, or robotics to be adopted, BIM must first be in place. This creates an adoption issue by itself. Additionally, other technologies like MT and drones are still new to the construction industry. There are much less success stories available for these technologies versus a technology like BIM, which is more widely adopted.

ET being in its infancy stage is double-sided. First, because these technologies are so new, they do not have economies of scale. Providers of technologies are trying to cover costs with a lack of buyers, so their costs are still high. This especially prevents teams with smaller projects for adopting the technology. Secondly, many teams are under-educated on what ETs are available – or what value can be provided to their project. By overcoming these barriers, ET will emerge from its infancy stage and more project teams will begin to adopt these technologies for their team’s benefit.

5.4 Large, Complex Projects

The findings from this research have shown that the ETs discussed here are primarily used in large, complex projects. This finding may have to do with the aspect of cost, and larger, more complex projects having the additional funding for these technologies. It may also have to do with larger projects having more decision makers who may have used these technologies in past projects. Regardless, this does not mean that ETs do not have a place in smaller projects. Given what has been learned in this research, it looks like there is an opportunity, which may just be prohibited by cost at the moment. However, there may just not be enough case studies to help prove said ET’s value. This is another double-edged sword, as case studies can only be completed once there are applications on smaller projects, which are minimal to date.

For example, MR/AR offer an engagement model that could help sell or lease units far in advance of completion of building works. It would be ideal, even if it were for a larger project, to understand the cost implications and benchmarks of carrying this out if BIM were already in place. If the results were successful, a case study or research paper highlighting these results may help convince a small project team to move forward with both BIM and MR/AR.

Another example is robotics. If there were a case study to show how efficient a robot can be at laying bricks, the total cost of implementing it might not matter. The rate in which the robot works, and the cost of labour saved may be enough for a smaller project team to adopt robotics not just for one, but many smaller projects, such as residential homes.

Lastly, drones are another example. Generally used on large highway projects or in large tunnel projects, there is also a great opportunity to adopt this technology for land surveying or for earthworks. Case studies or research papers that can compare efficiency to overall cost and labour saved may be helpful in attracting more project teams who oversee smaller projects.

Overall, ETs should not be limited to larger, complex projects. However, now, that is where most of the attention is coming from. Future studies can be done to understand benchmarking for these larger projects to try and make a case that these technologies can be affordable even on smaller projects. These future studies may be what puts these ETs in the hands of smaller project teams.

5.5 Environmental Impact

It is important to discuss environmental impact because some ETs are known to positively affect the environment. Throughout the literature review and expert interviews, several instances of environmental impact were found. Firstly, BIM was found to make environmental impact during the project planning phase. During this phase, BIM has been known to help with waste management and pollution control by implementing the process on projects. Secondly, robotics also makes an impact in this area by identifying how many bricks are needed on a masonry project. Robotics software can efficiently calculate materials needed can be used in other areas of the project, thus reducing waste. Thirdly, 3DP was found to make an environmental impact during the project executing phase. During this phase, 3DP was found to reduce material waste. Lastly, during the project closing/handover phase, BIM has been known to make an environmental impact by supporting the building life cycles. This allows for efficient operations of the building from its inception up until its demolished.

These are important instances to cite here because they were not included in the literature review. This is because the methodology for the literature review involved categorising ET impact by PMI’s PMBOK project knowledge areas, however environment is not yet included. It is however proposed to be included in the future. That said, these ETs providing environmental impact should not go unnoticed. There is much perceived value here, and given its proposed status, environmental should be considered here.

5.6 Future Studies

The purpose of this research project is to understand how ETs impact the value of construction projects. What has been discovered is that there are many ways in which ETs impact construction projects. However, the missing information is the value aspect. Through the literature review and primary data collection and analysis processes, the only thing identified is perceived or potential value. Actual value can only be understood by approaching the idea differently, while being very specific about the parameters of the study.

To understand if ET is valuable to construction projects, each type of technology would need to be studied independent of each other. These studies would need to be completed in the context of actual completed construction projects. For example, benchmarks would be collected from a similar, baseline project, where the ET being studied was not used. Additionally, a recently completed project where the ET was used would be studied and compared against one another. By siloing each type of ET in its own study, time, cost, and quality can each be measured for each specific technology. Together, these three constraints can help paint a clear picture of actual value realised on actual construction projects.

The first constraint that would be studied is time. The goal is to understand whether the ET being studied reduces the duration of a construction project. This could be studied by calculating a time efficiency percentage (budgeted project time / actual project time = time efficiency percentage). By comparing the time efficiency percentage from the baseline project to the project using ET, you can easily understand if the project using ET has performed more efficiently (faster). This approach to studying the constraint of time can provide results that show if there is actual value provided by the ET with respect to the time constraint.

The second constraint that would be studied is cost. The goal is to understand whether the ET being studied reduces the total cost of a construction project. This could be studied by calculating a cost efficiency percentage (budgeted project cost / actual project cost = cost efficiency percentage). By comparing the cost efficiency percentage from the baseline project to the project using ET, you can easily understand if the project using ET has performed more efficiently (cheaper). This approach to studying the constraint of cost can provide results that show if there is actual value provided by the ET with respect to the cost constraint.

The third constraint that would be studied is quality. The goal is to understand whether the ET being studied increases the overall quality of a construction project. This can be studied by interviewing key personnel involved in the project using ET. These personnel may include construction managers, project managers, labourers, and anyone who directly supervises the final work that is completed on site. These interviews would be qualitative research that would help understand, from the point of view of construction personnel familiar with the work, if the work completed by the ET offered higher quality output versus manual labour. This constraint would only be applicable to studies of ET that affect the physical work, such as 3DP or robotics. This is one approach to studying the constraint of quality which may be helpful for future studies.

What can be taken away from this study is that there is potential for ET to add value to construction projects. The only problem is that this study does not take the best approach to finding this information. This study is broad, which is the opposite of what future studies in this space need. Future studies need to silo ETs in their own studies, and with a targeted approach, actual results around value will be shown. This is not the ideal outcome for this study; however, it prepares future researchers on where and how to focus their efforts to help understand this problem of perceived versus actual value.

6. Conclusion

This research paper was undertaken as part of a research project as a capstone to the Master of Project Management and Master of Construction Practice dual degree at Bond University. The research topic is an interesting one that spans both degrees, which was a requirement when finalising the topic. The goal was to understand if there is a potential for ETs to add value to construction projects, and if so, how is this happening. The literature review provided vast insights into many ETs, the results were intriguing, and the discussion points were unexpected, but eye-opening.

The literature review undertaken for this research study provided many insights. Before delving into journal articles, the first thing that needed to happen was the identification of which ETs should be focused on. By exploring the internet for topics related to ET and construction, the following technologies were identified as important for this research: AI, AR/MR, 3DP, BIM, drones, MT, robotics, and VP. The next step was to find recent and relevant journal articles that reflected the impact these ETs have on construction projects. Many insights were found, and this process ultimately made this project more exciting given the relevance to the two master's degrees pursued that were previously mentioned.

The primary insights that were found from the literature review process was that there were overwhelming examples of how each ET benefits construction projects of all kinds. Insights such as time and cost reduction, increased productivity, positive environmental impact, better communications and increased health and safety are just some of the positive impacts these technologies have been proven to make on construction projects. These ETs studied were found to make the most impact in the project executing phase (forty-nine percent), followed by the project planning phase (thirty-one percent), the project controlling phase (eighteen percent) and the project closing/handover phase (two percent). ET was not found to impact the project initiation phase. In accordance with PMI's PMBOK project knowledge areas, the biggest area impact identified in this study were procurement (thirty-three percent), quality (twenty-four percent), resource (fourteen percent), scope (eleven percent) and cost (seven percent). The remaining knowledge areas were five percent or lower. Lastly, the breakdown of journal articles reflecting ET impact was balanced, with six to eight articles cited for each ET – apart from VP, which only had four articles cited. Overall, it was a successful literature review.

The method of collecting primary data was by means of interviewing experts in the areas of ETs previously identified. There were two options of choosing experts. First, contact people who work directly on real projects with experience with these ETs. Second, contact people who work in companies that specialise in selling these technologies/services, specifically where there is an application with construction projects. The latter was chosen for this study, and each expert was chosen on this basis. The two options were not mixed, as to provide a balanced study. The focus for finding experts was primarily in Australia, with some requests going overseas to the United States and Hong Kong. Twenty-five potential interviewees were targeted, and after a successful reply rate and acceptance of the interview, seven interviewees were scheduled to meet virtually via Microsoft Teams. All conversations were recorded using a handheld Sony recorder and transcriptions procured using Otter.ai application online. The interviews happened between 2nd July 2020 and 16th July 2020.

The results of the expert interviews were intriguing. The same Interview questions were asked of each expert interviewee, with the difference of each interviewee being asked about a different ET. Questions that were asked involved learning about the expert's experience with the technology. The next questions were all specifically regarding construction projects, including the impact made opportunities presented, challenges presented, general understanding of adoption difficulties or ease, and productivity impact. Additionally, a final question was asked of each expert regarding anything that was not covered that would be helpful for the research study. A lot of what was found during the expert interviews mirrored the information collected during the literature review. A lot of perceived value was identified, however given the expert interviewees role as leaders in the organisation selling the technology/service, actual value was not captured here.

The discussion captured the key findings from both the literature review and the primary data collection. There are a few key themes that were uncovered here. Firstly, BIM has been identified as a foundational ET for other ETs. VP, AR/MR, and robotics all rely on BIM as a foundation before those technologies can function. So, if there is a project team that wants to use these technologies, they will need to go through the BIM process. However, these ETs can be easily adopted if BIM is already in place. Secondly, the cost of adoption is a key factor as to why ETs are not adopted. Essentially, project teams have been provided a budget and ETs do not yet seem to be considered within the budgeting process. This vastly reduces the possibility of ETs being adopted, especially for smaller projects where proving return on investment may be difficult. Thirdly, ETs are still in their infancy. Even though there is a lot of perceived value, because ETs are still so new to construction projects, they are not at the foresight of many project teams. Additionally, finding team members who can positively back the value provided by ETs is slim, as they have not been used very much on projects to date given their infancy. Fourthly, ETs are mostly adopted on large, complex projects. This has to do with larger, complex projects having increased budget to afford the implementation of ET. Additionally, the complexity of these projects requires innovative approaches which opens the door to procuring ETs to solve problems. Fifthly, ETs provide environmental impact on construction projects. Even though PMI's PMBOK does not consider environmental a project knowledge area, it is still important to know that BIM, robotics and 3DP provide impacts in the areas of material waste reduction. Additionally, BIM helps to support efficient building life cycles.

The sixth and final piece of the discussion highlights opportunities for future studies in this field. This is an essential section, because this research study did not make any conclusive findings on value provided by ETs in a construction project context. Perceived value was the only things identified through both the literature review and primary data research. That said, recommendations have been made for future researchers in this topical area. The most important recommendation is for future studies to study each ET independently. Within each independent study, it is critical to review literature on the sole ET being studied and only interview people who are directly working on a project that implemented this ET. It is critical to gather quantitative data on actual versus budgeted cost and time, and qualitative data on quality. The goal would be to compare the success of the project employing an ET versus a historical, similar project that did not. If there is an increase to the benchmarks from the historical project, this may prove the ET provided actual value to the project. Measuring and comparing time, cost and quality is critical to finding proof and answers to the big question that this interesting research topic provides.

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