TOWARDS THE IMPLEMENTATION OF IMMERSIVE TECHNOLOGY IN CONSTRUCTION – A SWOT ANALYSIS

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SUMMARY: Whilst research of immersive technology has been growing, substantial efforts thus far have been scattered. Conflicting ideas and arguments from scholars provoke uncertainty and questions about the validity of these outputs in fostering more extensive implementation of immersive technology in the construction industry. Consequently, the direction for further developments in research remains unclear. This study aims to identify the status quo of immersive technology adoption in construction. A systematic review with thematic analysis was conducted. Common themes and concerns about the use of immersive technology in the construction are classified under the framework of SWOT (strengths, weaknesses, opportunities and threats). The results indicate that whilst 'strengths' and 'opportunities' display a broad array of applications and functions that are derived from real benefits, a substantial amount of opportunities mentioned are driven by optimism. Alternatively, the results from 'weaknesses' and 'opportunities' identify several limitations involved in the uptake of immersive technology in the construction industry. Findings of this study provide vision that can help direct resources to those measures that can best meet the needs of construction industry. It is suggested that future resources are better to be put on integration with proven effective systems like Building Information Modelling (BIM) and Computer Aided Design (CAD) software. New developments should due consider the real demand of the industry.

KEYWORDS: Immersive technology, construction, augmented reality, virtual reality, mixed reality, SWOT, systematic review

1. INTRODUCTION

Immersive technology blurs the boundary between the physical and virtual worlds, enabling a sense of immersion experienced by the users (Lee et al., 2013). With the government interventions and the investments from some large construction organisations, the use of immersive technology in the construction industry has been advocated with the aims to improve productivity, site safety and achieve sustainability (Kamat & Martinez, 2003). In the construction research field, Dunston & Wang (2011) adopted the concepts of 'virtuality continuum' developed by Milgram & Kishino (1994) to define immersive technology. They defined immersive technology as a continuum, with one end displays a 'real environment' whereas the other end exhibits a 'virtual environment'. The range developed demonstrates that immersive technology can be in different forms with different portions of real and virtual elements presented on a single display (Wang & Dunston, 2011). Over the years, immersive technology has been refined into three major forms - virtual reality (VR), augmented reality (AR) and mixed reality (MR). They blend computer-generated virtual objects and the real environment in different extents with the assistance of three-dimensional registration and real-time interactivity (Pribeanu et al., 2017).

Whilst the term immersive technology has been rarely used, AR, VR and MR appeared more frequently in the construction-related publications. Relevant AR, VR or MR techniques are being suggested to be integrated with many of the current systems, regardless of its popularity in the construction industry (Nobuyoshi et al., 2004). For example, Kivrak & Arslan (2018) outline new onsite construction practices where AR technology provides step by step processes via simulation to perform job-specific tasks safely. Nobuyoshi et al. (2004) explore VR and portray the immersive environment as a context that creates the opportunity for individuals to enhance visualisation regarding building design. On the other hand, Dunston & Wang (2005) investigate MR as a tool to assist the process of structural building design. Further examinations explore implications in building services design and utilise immersive technology to locate and identify services to prevent design clashes and inefficiencies. Other scholars have investigated the adoption of VR or AR in conjunction with commonly used construction software such as Computer Aided Design (CAD) and Building Information Modelling (BIM) (Getuli et al., 2018, Dong et al., 2013). Getuli et al. (2018) explore how Building Information Modelling (BIM) can integrate with VR, highlighting how an immersive environment can potentially assist the effective management of risks and safe practices on site. Similarly, Dong et al. (2013) review the implementation of AR and VR technology in conjunction with Computed-Aided Design (CAD) software to create a visual environment to identify and solve design issues. With a broad range of applications already being suggested, there is no questioning that AR, VR and MR have the potential to enhance numerous construction-specific processes. Notwithstanding, whether studies examined a collaboration with BIM and/or CAD, or the development of a brand new immersive software, AR, VR and MR techniques thus far have not been extensively implemented in the construction industry (Mo et al., 2014).

Whilst some relevant comprehensive literature reviews were conducted, scholars of these studies often adopt unique approaches in selecting and reviewing VR, AR and MR related publications, dependent upon their research purposes (Elshafey et al., 2020, Fenais et al., 2020). To state a few, Guo et al. (2017) and Xiao et al. (2018) focus on reviewing VR/AR in construction safety. Fenais et al. (2020) reviewed how AR were applied in underground construction. These review studies shared some common grounds, indicate that VR, AR and MR have great potential to be applied more extensively in the construction industry. Nonetheless, the effectiveness of implementing immersive technology into the construction sector is not fully understood. Furthermore, previous studies (including those with comprehensive reviews) lack a holistic approach to understand the current state of immersive technology implementation within the industry (Xiao et al., 2018). This makes it difficult to move forward to fostering more extensive and effective implementation of immersive technology in the construction industry.

This paper seeks to fill the research gap through conducting an in-depth systematic review with thematic analysis. More specifically, this study aims to identify the status quo of immersive technology adoption in construction. Findings of this review study can help the industry to understand how immersive technology may have been integrating with the existing construction practice. While investments in immersive technology were noted, this study helps the practitioners to identify where are the resistance from. In academic perspective, findings of this study help uncover the drivers of the immersive technology implementation. This can provide vision to help direct resources to develop measures/tools that can best meet the needs of the construction industry. This study is innovative in its approach to investigate the status quo of immersive technology adoption in construction. The outcomes are to be articulated by using a force-field diagram that will help break a grid lock of more effective implementation of immersive technology.

2. RESEARCH METHODOLOGY

A systematic review of the literature (including refereed journals, conference proceedings and industry reports), is the methodology chosen for this study. The methods involve a thematic analysis whereby a SWOT analysis was conducted to provide a holistic overview of immersive technology and its application in the construction sector. The acronym 'SWOT' stands for strengths, weaknesses, opportunities, and threats. To enable an in-depth and detailed review, NVivo was adopted as a tool to retrieve data for analysis. Figure 1 articulates the systematic review approach adopted in this study.
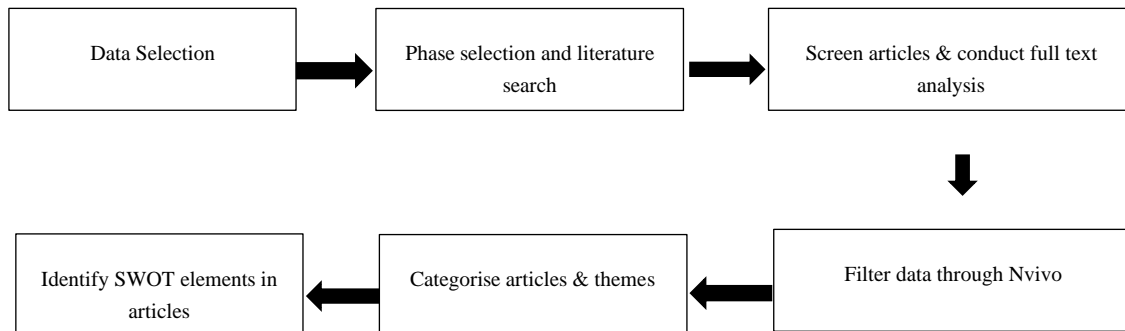
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│  Data Selection │ ───▶ │ Phase selection and │ ───▶ │ Screen articles & conduct │
│                 │      │ literature search   │      │ full text analysis        │
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┌─────────────────────┐      ┌──────────────────────┐      ┌──────────────────────┐
│ Identify SWOT       │ ◀─── │ Categorise articles  │ ◀─── │ Filter data through  │
│ elements in articles│      │ & themes             │      │ Nvivo                │
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Figure 1: Systematic review approach of this study

A systematic review is an overarching methodology that involves the objective, replicable and transparent approach of examination. This is described as a unique tool for establishing boundaries of a given subject (Bapuji & Crossan 2004). It has been identified that some previous literature review studies were influenced by the authors choice and judgement when selecting relevant papers. Therefore, this study started with an objective electronic search for peer-reviewed journal papers to prevent selection bias. Moreover, the search was conducted across multiple world-recognised databases, including Scopus, Science Direct, Proquest, Emerald, SpringerLink and Wiley. Bapuji & Crossan (2004) confirm the effectiveness of an objective approach to determine relevant publications and therefore databases on a given topic. Considering its relevance, a systematic literature review is commonly used in construction research that aims to identify applications, barriers and potential future research directions (Guo et al., 2017; Xiao et al., 2018; Woksepp & Olofsson, 2008; Getuli et al., 2018).

Thematic analysis is one of the methods that can be adopted for the systematic review. It is a form of descriptive qualitative analysis. It is described as a flexible and useful research tool, providing a rich and detailed, yet complex, account of the data (Braun & Clarke, 2006). Scholars further identify the suitability of this methodology for answering questions regarding why people 'do' or 'do not' adopt a particular service (Guo et al., 2017). This approach has been deemed as the most effective for this specific study to address the adoption of immersive technology in the construction industry. With large amounts of data, a thematic analysis will explore the similarities and themes across the different articles analysed.

In this study, the analysis of articles by thematic analysis was assisted and displayed through a SWOT analysis matrix as seen in Figure 2.

	Helpful	Harmful
Internal: Technology related	**STRENGTHS**	**WEAKNESSES**
External: Context of application	**OPPORTUNITIES**	**THREATS**

Figure 2: SWOT Analysis Matrix

As per the matrix shown in Figure 2, a SWOT analysis is categorised into internal and external factors. In this scenario, internal factors explicitly related to the strengths and weaknesses of each form of immersive technology, and external factors referenced opportunities and threats regarding market suitability in the construction sector (Gurel & Tat, 2017). Helms & Nixon (2010) describe the interrelationship of the internal and external elements of SWOT as strengths that can be leveraged into new opportunities, and weaknesses that lead to potential threats can be recognised and evaluated. By addressing capabilities within the proposed environment of the construction industry, this methodology is deemed highly suitable for providing a holistic review.

3. DATA COLLECTION

A literature search of peer-reviewed journal articles via electronic databases was conducted. Figure 3 outlines the key steps to identify the relevant articles utilised in the systematic review.
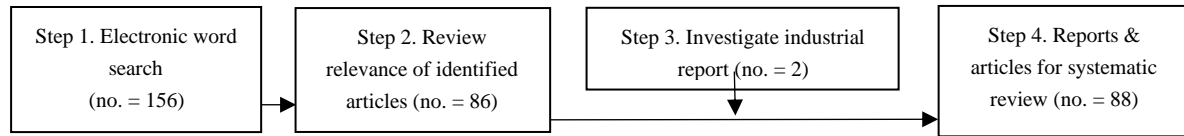
| Step 1. Electronic word search (no. = 156) | Step 2. Review relevance of identified articles (no. = 86) | Step 3. Investigate industrial report (no. = 2) | Step 4. Reports & articles for systematic review (no. = 88) |

Figure 3: Data collection process

In step 1, the following search terms and its derivatives were used: 'virtual reality' OR 'augmented reality' OR 'mixed reality' OR 'immersive technology' AND 'construction'. The derivatives of 'construction' includes: 'construct', 'build', 'architect', 'building design', 'builder', and 'construction contractor'. The concept of immersive technology in the construction sector was introduced around 1996 and the databases were searched for articles published between 1996 and 2020. This resulted in a total of 156 articles identified in the first step. Figure 4 shows that the trend of scholarly research regarding immersive technology in construction has been increasing.
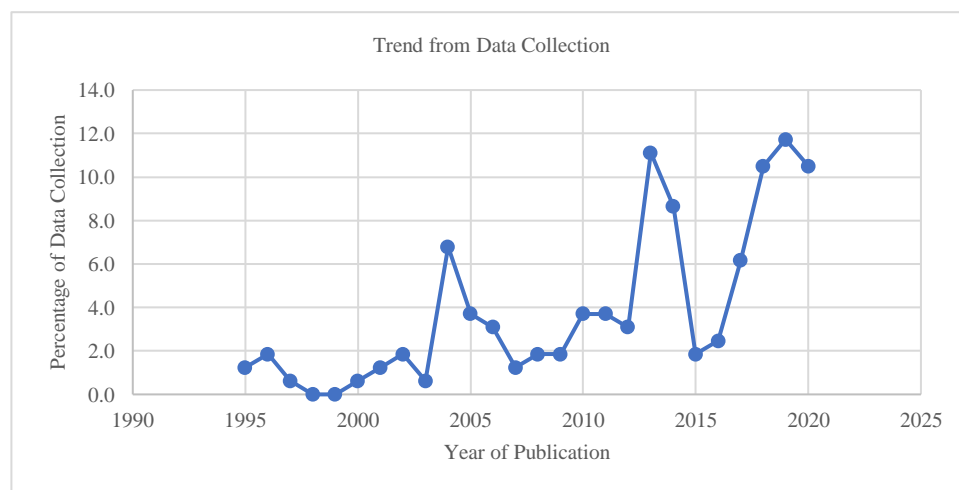

Figure 4: Data collection trend regarding year of publication – step 1

In the next step, the relevance of the identified articles was checked through reading the articles' abstract. Articles that were irrelevant to AR, VR and MRs' strengths, weaknesses, opportunities, and threats were excluded. For example, articles that did not reference construction related activities were immediately disqualified. A common example of disqualification was the use of VR, AR or MR integrated into higher education for those studying architecture, construction, or engineering in a university context. From the filtering process, 86 out of the 156 articles were assessed as relevant and are included in the analysis in step 4.

It is noted that the aforementioned electronic search process may not cover some potentially important industry-based reviews. As a remedy, an additional search was conducted to include official reports published by the professional institutes and government bodies in step 3 of the search process. An additional two industry reports were discovered. The low number of relevant industry reports demonstrate the lack of comprehensive studies and robust plan regarding future direction and implementation of immersive technology in the construction industry. As a result, 88 publications are included in this systematic review to study the strengths, weaknesses, opportunities, and threats of immersive technology adopted in the construction industry.

4. RESULTS AND DISCUSSION

4.1 An overview of the results

Eighty-eight publications were analysed through NVivo where each article was thoroughly read through to capture sentences describing either strengths, weaknesses, opportunities, or threats regarding immersive technology in construction. This data was grouped into categories using NVivo by creating nodes of 'strengths', 'weaknesses', opportunities' and 'threats'. This procedure followed strict keywords search of determining elements of SWOT to ensure continuity and reliability across all 88 publications (as outlined in Table 1). It is important to note that even though some publications reference SWOT in the broader context of other industries, only content relevant to the construction industry was identified for data analysis. SWOT elements that was duplicated or deemed similar stated within a single article were only counted once to avoid duplication of coding.

Table 1: Keyword search under SWOT framework

Elements	Keywords
Strengths	'Strength', 'Advantage', 'Benefit', 'Improved', 'Enhanced', 'Improvement', 'Enhancement'
Weaknesses	'Weakness', 'Disadvantage', 'Shortcoming', 'Limitation'
Opportunities	'Opportunity', 'Potential', 'Future', 'Recommendation', 'Recommended action'.
Threats	'Threat', 'Challenge', 'Barriers', 'Obstacle', 'Risk'

In addition to the 'keyword' search, the ability to understand the context and perspectives of the articles was critical when determining which element of SWOT was most suitable. For example, 'potential benefit' or 'strength' described in the articles may be more appropriate to be classified as the 'opportunities' because the context of the respective findings was developed in a controlled environment which practicality in real construction projects was not justified. Typical examples that involved further judgment include a study conducted by Shi et al. (2020) whereby simulation site activities were conducted in a well-controlled laboratory environment. As the reported 'site activities' had never been happened in the real construction sites, the strengths that were claimed in this study were classified as the 'opportunities'. Another example can be found from a study of Chalhoub & Ayer (2018) where MR technology was utilised to develop 4D as-built models to monitor site activities and enhance safety. As the developed models have yet to be attested in real construction environments, those portrayed strengths were classified as opportunities in this review study.

Threats is another element where qualifications for applicable content extended beyond the keywords presented in Table 1. This included data that focused on aspects of the technology in its current form that act as a hindrance or could potentially prevent uptake of technology in a construction-related application. Ahmed (2018) and Woksepp & Olofsson (2008) explore one example impeding technology uptake for the construction sector stating that technology lacks technicians required for adoption and ongoing maintenance needs. Therefore, any flaws or limitations regarding AR, VR and MR that have the potential to be resolved or improved in the future was classified a threat. Another example is from Delgado et al. (2020) who outlined the weaknesses of existing hardware and software, but did not provide logical suggestions for issues to be rectified. Consequently, weaknesses were limited to the known disadvantages of technology when applied in the construction industry.

Table 2 below outlines the frequency of 'strengths', 'weaknesses', 'opportunities', and 'threats' referenced from the 88 publications. The results indicate that scholars have reiterated and made reference to the known strengths of implementing AR, VR and MR in construction with 395 times (47%) in 65 out of the 88 analysed publications. As technology has had slow and little uptake, 'social acceptance' (Pratama & Dossick, 2018) is still a challenge as the perception of many industry stakeholders is that technology is still immature for adoption as the benefits do not outweigh weaknesses (Delgado et al., 2020). As a result, the advantages of technology are frequently investigated and confirmed. For example, Le et al. (2015) verify that traditional training experiences are enhancing by supporting perception and spatial awareness through technology in a construction environment.

Table 2: NVivo SWOT references

Element Name	No. of publications referenced	Frequency of referenced	% of references
Strengths	65	395	47%
Weaknesses	52	138	16%
Opportunities	71	194	23%
Threats	48	119	14%
Total		846	100%

The second most frequently referenced element is opportunities, with 194 times of references (23%) captured from 71 out of the 88 relevant publications. Scholars usually speculate the potential useability of AR, VR and MR or convey benefits in a highly simulated and controlled environment outside construction. For example, Wolfartsberger (2019) describes the potential of technology but are yet to evaluate the validity of conducting tests in a laboratory environment rather than real-world settings. Due to the limitations of these studies, many remarks are restricted to being classified as an opportunity that is yet to be confirmed in a real construction context.

Threats and weaknesses alluded to are less frequently referenced as compared to strengths and opportunities. Papers that were highly applicable with multiple threats and weaknesses were articles investigating the detail of specific AR, VR and MR technologies and software being developed and tested. For example, Liu et al. (2020) and Delgado et al. (2020) focus on specific technology available for construction. Subsequently, hardware issues, including quality of goggles, battery life of devices, and suitability to use on-site, were highlighted. Consequently, limitations and flaws of technologies form a significant part of the discussion of papers as technology is still being adapted to the functions required in construction.

4.2 Sub-themes under Strength

The next stage of the analysis refined data within each element by creating sub-themes. Sub-themes were determined by reviewing all references and developing relevant heading to categorise data. All nodes under SWOT were examined and allocated to the appropriate sub-theme. Although the elements of SWOT have been refined into distinct categories, it is critical to understand that sub-themes are interrelated, and one will cause or influence another category. For example, the topic 'perception and understanding' located with strengths have a flow-on effect towards improving 'problem-solving and decision making', another sub-theme under strengths. Where applicable, data was allocated to multiple categories.

Seven sub-themes are identified under 'Strength'. They are presented in Table 3 in descending order of the frequency of references. By a substantial margin, the most frequent strength is 'perception and understanding' with 126 references across 51 out of the 88 articles. This can be described as improved knowledge and understanding regarding construction concepts and design. Wang et al. (2018) affirm that VR is a valuable tool proven to provide a better understanding through visualization capabilities effectively. Shin & Dunston (2009) state that visualization in the form of immersive technology improves spatial awareness and reduces the cognitive load required to interpret complex construction information. Wang et al. (2018) and Zaher et al. (2018) demonstrate the effectiveness of immersive technology interpretation through conducting a comparison to traditional methods such as 2D paper drawings where immersion was deemed significantly superior. As a result, it is noted that the strength 'understanding and perception' has a significant flow-on effect of developing the other sub-themes.

Increasing 'productivity' is frequently discussed as the strength of implementing immersive technology in the construction industry (referenced on 72 occasions). Furthermore, productivity and simulation generated an overlap of data across a range of topics. For example, Delgado et al. (2020) describe the simulation of high-risk activities and the use of expensive equipment as a means to enhance worker safety and productivity. Zhao & Lucas (2015) further explore this in an education context confirming simulation produces real-world scenarios without any repercussions. 'Productivity' is highly relevant to the sub-theme 'Information Delivery via Simulation' referenced 71 times from 27 papers. For example, Liu et al. (2020) demonstrate that simulating the occupancy and movements within a future building can be beneficial to determining the elements of design within the building. The many settings applicable for delivering immersive data via simulation communicates the various stakeholders that can reap the learning benefits through a new platform.

'Problem-solving and decision making' are both ranked fourth (was referenced 68 times). In some applications, the use of an immersive display instantly resolved concerns and conflicts, particularly in a design context (Lui et al., 2020). For others, immersive technology prompted resolution of errors and allowed for quick decision making (Alizadehsalehi et al., 2020 & Fu & Liu, 2018). In addition to the ability for technology to aid decision making, data indicated that immersive technology could control and monitor numerous project management tasks including site progress monitor, task forecasting and defect management. Wang et al. (2014) explore site progress monitoring demonstrating how real-time workspace visualisation enables project managers and other applicable stakeholders to review building progress and forecast projects more effectively. In contrast, Boton (2018) investigates the same application of building monitoring, however, demonstrates the ability to identify deviations and errors in works that can be quickly rectified and in some cases, eliminated. This sub-theme is usually discussed together with another sub-theme 'project management' (found from 28 publications that was refenced 64 times).

Table 3: SWOT results under strengths

Sub-themes	Description of sub-theme	No. of articles	Freq. of ref.	Representative quote
Perception & Understanding	Improved understanding of construction and design of all stakeholders irrelevant to prior knowledge.	51	126	"4D simulations are particularly useful for the client to visualize and understand the building process before committing to a project" (Boton, 2018).
Productivity	Increased onsite productivity and performance through reduced man-hours and errors.	35	72	"The VR system allowed for a much faster entry into the design review" (Wolfartsberger, 2019).
Information Delivery via Simulation	Improved learning and education through the capacity to mimic the real world without the concern of the repercussions.	27	71	"The best way for training and learning was to do the real thing and to simulate the real tasks to obtain experience" (Zhao & Lucas, 2015). "It can be implied that the first-hand experience from real-life tasks and the contrived experience from representative simulations are the most effective learning styles" (Zhao & Lucas, 2015).
Problem Solving & Decision Making	Enhanced knowledge improving team. Collaboration and more effective design making.	32	68	"Virtual Reality (VR), have been designed to provide better conditions to collaborative decision-making and problem solving in the conceptual design phase" (Paes et al., 2017).
Communication	Enhanced communication and interactivity between stakeholders.	29	68	"Permits real-time virtual collaboration for stakeholders from different locations" (Alizadehsalehi et al., 2020).
Project Management	Ability to improve management activities through enhanced project monitoring, reviewing, and forecasting.	28	64	"Omission error and dimension deviation of many defects in the construction site can be prevented proactively using AR techniques" (Park et al., 2013).
Enhancing Existing Software	Enhancement of existing technology such BIM & CAD.	24	43	"VR and BIM enable architects and designers to better communicate design within the team members and with the client" (Sampaio, 2018).

'Communication' is ranked fifth (referenced 68 times), with many scholars describing technology as a tool to facilitate communication (Lui et al., 2020). Alizadehsalehi et al. (2020) further develops this benefit demonstrating that real-time virtual environments permit the collaboration of multiple stakeholders both locally and across different locations. Similarly, Maftei et al. (2018) verify that virtual mock-ups promote conversations which in turn leads to valuable discussions surrounding problem-solving.

The final sub-theme identified through the thematic analysis is 'enhancing existing software' which is referenced only 43 times across 24 papers; however substantial enough to be included in the findings. This refers to immersive technology, enhancing the features and data produced from existing construction related software such as CAD and BIM. Wang et al. (2018) employ the collaboration of BIM and VR to be advantageous as modelling can reflect and detect real-time construction changes. Similarly, Olbrich et al. (2013) review the collaboration of BIM data and augmented reality as a means of data collection to aid monitor buildings works. Although this data demonstrates proven advancements in existing construction technology, many of the findings referenced do not demonstrate a pathway of integration between existing and immersive software. Consequently, these claims may appear contradictory to other papers where integration is deemed highly problematic (Wang et al., 2018 & Goulding et al., 2012). As a result, many scholars investigate this limitation which forms the majority of findings within the 'weakness' and 'threats' results.

4.3 Sub-themes under Weakness

Five subthemes were identified under 'Weakness' (refer to Table 4). The most prevalent weakness is the 'limitations of technology'. Appearing 59 times in 31 articles, 'limitations of technology' refers to the constraints regarding the functions and suitability of immersive software specifically in a construction environment. This subtheme is usually reported together with the problem regarding the 'collaboration with existing software' (referenced 32 times in 18 publications). It is important to note that no singular software was recommended or

deemed superior in a construction application. Moreover, some of the software recommended were self-created, all demonstrating unique flaws in a construction context. This includes inaccurate registration of virtual objects due to limiting tracking and calibration technologies (Shin & Dunston, 2008), the absence of supporting real-time data synchronization and the inability to interactively manipulate design through VR applications (Du et al., 2018) to name a few. In addition to this, Sulbaran & Shiratuddin (2006) highlight a substantial restriction in an electrical installation training environment, confirming that stringent pre-programming in this scenario impacted the ability for software to be manipulated for use. As a result, movement between systems is time-consuming hindering previous conclusions proposing AR and VR quickly enabling the visualisation of BIM data on-site. Due to its prevalence, 'time' (referenced 24 times in 18 publications) was identified as another sub-theme. In this scenario, time, or time-consumption, incorporated the commitment required to develop virtual worlds and update design as required.

Table 4: SWOT results under weaknesses

Sub-themes	Description of sub-theme	No. of files	Freq. of ref.	Representative quote
Limitations of technology	Limitations of technology impacting functions and suitability for construction applications.	31	59	"A limiting factor of current AR devices and some VR mobile devices is the limited capacity to load large and complex models" (Delgado et al., 2020).
Collaboration with existing software	Integrating technology with existing systems such as BIM and CAD.	18	32	"There is still a lack of sufficient investigations or insights on how BIM can be integrated with AR" (Wang et al., 2014).
Procurement	Resources and costs associated with procurement of technology.	19	28	"The highest-ranked limiting factor was expensive hardware and training" (Delgado et al., 2020).
Time	Necessary time for effective implementation and monitoring of technology.	18	24	"The development of VR and AR system contents was considered time consuming and laborious" (Le et al., 2015).
Usability & applications	Usability and functions within the construction field.	16	22	"Architectural scale model cannot instantly re-generate new model when design changing" (Wang et al., 2014).

The next category is 'procurement', appearing 28 times in 19 papers. Interrelated with the subtheme of time, procurement is an umbrella term that describes the lack of resources and systems available to support the uptake and ongoing use of technology. Findings convey key examples including the unknown of software in the market (Delgado et al., 2020), limited training in technology (Dallasega et al., 2020) and expensive hardware and equipment (Alizadehsalehi et al., 2020). Due to these disadvantages, the adoption of technology is time-consuming and noted as unpractical. As a result of these findings, commentary surrounding the usability of immersive technology appeared referenced 22 times in 16 articles creating the sub-theme 'Usability and applications'. This identified the constraints that influence ease of use and ability to utilise across many applications. For example, Wen & Gheisari (2020) explain the skills required to script virtual worlds, whereas Delgado et al. (2020) confirm that existing software limits the ability to share and collaborate within virtual worlds easily. Consequently, many of the identified sub-themes describe a weakness that acts as a catalyst when brought into a construction environment. As a result, immersive technology may appear as a technology platform that is not yet user friendly (Delgado et al., 2020).

4.4 Sub-themes under Opportunities

'Opportunities' describe the potential of immersive technology in construction that is yet to be proven in a real application. As a result of this, more sub-themes were developed as numerous scholars propose a range of potential benefits for immersive technology (refer to Table 5). Consequently, some scholars limit their findings and results in specific applications for technology rather than investigating the potential benefits or disadvantages. Though this is not the focus of the paper, data has been captured stating that AR, VR and MR are deemed most suitable to aid the design phase of the project, referenced in 30 publications (Dong et al., 2013, Dunston & Wang, 2005).

The majority of sub-themes discovered under 'opportunities' share categories outlined in findings under the results of 'strengths'. These common themes included 'education & understanding', 'Training and simulation', 'productivity', and 'planning & scheduling' capabilities. Their frequencies, including cited examples, are

displayed in Table 5. Some results indicated 'Opportunities' as the already known 'Strengths'. Such findings are understandable for the fact that our data parameter includes papers from the last 20 years. With continuous effort made by the researchers in advancing the use of immersive technology, some previously known as "Opportunities" in a decade ago may have already become the "Strengths". Furthermore, it explains how some researchers have been restricted in previous years when it comes technology implementation and testing in a real environment or context that replicates a construction environment and all its complexities (Albert et al. 2014).

Table 5: SWOT results under opportunities

Sub-themes	Description of sub-theme	No. of files	Freq. of ref.	Representative quote
Education & understanding	Technology enhancing understanding and complex knowledge.	33	45	"Studies have indicated that Virtual Reality (VR) environments have the potential to assist and enhance user's learning experience" (Sulbaran & Shiratuddin, 2006).
Software integration	Integrating immersive software with existing software such as BIM and CAD.	25	45	"CAD and VR could be regarded as complementary technologies in design visualization" (Woksepp & Olofsson, 2008).
Productivity	Improved productivity and more efficient methods of construction and management.	25	32	"VR has a big potential to accelerate the design review process with a shorter training period" (Wolfartsberger, 2019).
Training & simulation	Technology enabling a new platform for education and training by simulating construction environments.	25	32	"Schematic visualization techniques are usually provided as added functionality in simulation tools" (Rekapalli & Martinez, 2011).
Planning & scheduling	Technology providing the capability to assist scheduling and forecasting activities.	20	30	"AR could be effectively used for the safety task scheduling in a construction project" (Ahmed, 2018).
Design & applications	Specific application and tasks that could be highly beneficial.	16	30	"Whilst many VR techniques can be incorporated into future building design tools for rapid prototyping of design" (Whyte et al., 2000).
Communication	Communication and collaboration between stakeholders.	24	29	"VR training tool for the electrical systems is proposed to overcome the problem of 'dysconnectivity' between electrical designers and builders" (Sulbaran & Shiratuddin, 2006).
Development of technology	Recommended alterations to technology to improve useability and functions.	8	10	"Our priority in future works is to fix this issue in order to be able to use, not only walkthrough-based constructability analysis, but also timeline-based capabilities" (Boton, 2018).

The findings do, however, support the weakness outlined regarding software integration. Referenced 45 times under the category 'Opportunities', many scholars acknowledge; first, the lack of, then the needs for software collaboration. Gheisari & Irizarry (2016) support this understanding communicating the need for seamless integration with other software systems without the burden of additional programming interventions and systems. Chalhoub & Ayer (2018) further support this technical limitation confirming that technology in its current form lacks technical specifics necessary for the significant uptake.

Although results from opportunities do not present any new ground-breaking information, it does support previous data findings. As a result, many of the proposed benefits are beginning to become real finding, evident through the continuity of sub-themes between 'strengths' and 'opportunities'. Therefore, the direction and application in construction are clear, however, the limiting parameters surrounding immersive technology are confirmed to be problematic,

4.5 Sub-themes under Threats

Five subthemes were identified under 'Threats' (refer to Table 6). 'Suitability and limitations of technology' ranked first, with 66 references from 36 publications. This category has two elements, suitability, and technology limitations. Scholars suggest the suitability of immersive technology in the construction industry is still unknown, as Delgado et al. (2020) questioned the maturity of technology for practice in an industry known for its complexity. Delgado et al. (2020b) concluded that current technologies are not advanced enough to be applied effectively on

real construction projects but rather suitable for entertainment. On the other hand, the limitations of specific hardware and software constraints that prevent usage in certain construction applications. Park et al. (2013) discuss the limit of markers that influence data accuracy, whilst Chalhoub & Ayer (2018) highlight the conflict of specific immersive hardware and mandatory onsite PPE. These limitations lead to the second most frequent sub-theme 'adoption and integration' with 42 references in 23 different publications. This subtheme refers to the ease and ability to adopt the technology into the existing environment. Kim et al. (2017) confirm that cost is highly influential when adopting technology due to expensive hardware and training. Furthermore, Delgado et al. (2020b) note that it is difficult for firms to justify the financial burden as potential benefits are still unclear. In conjunction with this, Whyte et al. (2000) highlight the issue of integration with existing systems, including BIM and CAD, which is deemed problematic. Shin & Dunston (2008) state that the technology in its current form is not advanced enough to be effectively adopted into real construction sites.

Table 6: SWOT results under threats

Sub-themes	Description of sub-theme	No. of files	Freq. of ref.	Representative quote
Suitability & limitations of Technology	Suitability and limitations of existing hardware and software in the construction field.	36	66	"AR and VR technologies are perceived as technologies for entertainment and with limited potential for complex engineering activities" (Delgado et al., 2020).
Adoption & Integration	Factors that hinder the ability for technology to enter the construction field and its existing systems and processes.	23	42	"There is still a lack of sufficient investigations or insights on how BIM can be integrated with AR" (Wang et al., 2014).
Research Environment	Context of testing environment that can impact the validity of results. Eg. controlled simulations.	18	27	"There remains little AR research that includes testing with actual industry practitioners using current standards" (Chalhoub & Ayer, 2019).
Time & Resources	Time and resources required to effectively implement technology	9	22	"The first challenge was the complex scripting process required to build games" (Wen & Gheisari, 2020).
Awareness of Technology	Awareness and education surrounding technology in the construction field.	10	14	"Many AEC organizations lack expert knowledge to properly leverage AR and VR technologies" (Delgado et al. 2020).

The remaining three sub-themes, 'research environment', 'time & resources', and 'awareness of technology' were less frequently referenced with 27, 22 and 14, respectively. Although these sub-themes were not discussed in-depth in previous studies, data provides critical commentary that should not be overlooked. This includes questioning the validity of previous studies (research environment), in particular their benefits which is a significant topic as many scholars such as Goulding et al. (2012) conduct testing in a controlled environment. In these scenarios, the research environment does not replicate a construction site that poses many variables. Goulding et al. (2012) outline this in his paper, acknowledging the testing environment to be optimal with no external interruption. These findings display an overlap with the results discovered under 'Weaknesses'. Similarly, the accuracy and validity of findings can be viewed as questionable.

5. DISCUSSIONS OF FINDINGS

This study involved a thematic analysis of peer-reviewed conference papers and journal articles, and industry reports. Generally, the conference papers are mostly conceptual or introductory that did not show much evidence outlining the real applications of immersive technology. Some provided concepts of how these technologies can be applied, rather than how it can be adopted more extensively. Others promoted the ideas of specific applications; however, they did not provide any evidence to prove their applicability and practicality. On the other hand, industry reports focus more on the direction and trend of immersive technology within the industry. They firstly outline what is happening in the industry and discuss the difficulties and weaknesses of the technology, but did not provide any recommendations or a pathway for its resolution.

Subsequently, contents from the journal papers are more relevant with stronger justification and empirical work being carried out. SWOT themes and their sub-themes can be clearly identified from these papers. Authors of these articles either emphasised on a broad focus towards technology opportunities highlighting specific applications, or a detailed investigation regarding the technology and software systems utilised for construction environments. Some reported studies provided real testing applications which outlined real and potential benefits

to technology. It is worth noting that immersive technology is influential when it is integrated with existing construction practice. In particular, successful cases have been mounting in integrating VR and AR in BIM and CAD. Nonetheless, there has been a lack of evidence justifying the success of utilising VR, VR or MR as a standalone product.

Results from the SWOT analysis (summarised in Figure 5) indicate that the use of immersive technology has been viewed as an adequate direction to enhance knowledge and understanding, as well as improve communication, collaboration and problem-solving. While most of the papers emphasise the potential of immersive technology, challenges like the applicability in real construction project environments, their rate of adoption, only very few authors addressed and admitted the difficulties faced by practitioners in technology adoption. Discussions about how immersive technology may disrupt/affect conventional operations and procurement were scarce. Though most publications amid optimism about immersive technology, a balanced understanding for use in construction may be limited. As such, this explains the necessity to investigate the 'weaknesses' and 'threats' in this holistic review.

The results of 'weakness' and 'threats' demonstrate an interrelation and shared common themes across the two categories. In particular, what is deemed as a current 'weakness' of immersive technology is often reiterated as a potential 'threat' regarding the uptake of technology. A prevailing concern is that the research environment contradicts many optimistic remarks of technology. With the due caveat of 'weaknesses' and 'threats' results obtained from controlled environments such as a laboratory; many scholars initially question the validity of the potential advantages before providing suggestions for improvement for future investigations. For example, research was conducted on real construction sites or environments that simulate a construction site, including its parameters and complexities. Evidently, these scholars do admit the weaknesses of existing understanding, often describing observations as limited. Though the direction for reliable findings is outlined, the practicality and reality of their suggestions are highly complex and logistical in its application. In this context, the proposed pathway for future research predominantly discussed under 'threats', can be noted as a perceptual understanding rather than conceptual. Practical implementation in a research environment let alone a real application is still in question. As such, the full extent of immersive technology and its effectiveness in construction is not fully understood.

Results of the SWOT analysis indicate that immersive technology has great potential to integrate with BIM and CAD effectively. Nonetheless, immersive technology in its current form may lack the specificity and functions required for practical use in the construction industry. Literature reveal that researchers are inclined to develop their own AR, VR or MR systems to integrate with BIM and CAD. Nonetheless, in their studies no singular or universal software platform has been mentioned or recommended. The inability to seamlessly integrate and interchange data between immersive technology and existing systems are reported as highly problematic and, in some cases, prevent many of the mentioned advantages when adopted. This prompts the discrepancy of software integration with BIM and CAD appearing as both a 'strength' and 'weakness'.

Strengths	Weaknesses
• Enhance knowledge and understanding. • Effective information delivery and learning through simulation. • A tool to aid and improve communication, collaboration and problem-solving.	• Existing parameters of technology restrict construction use to limited applications. • Collaboration and communication with BIM/CAD are limited and inefficient. • The procurement and ongoing maintenance of technology are restricted in its support.
Opportunities	Threats
• Ability to deliver complex understandings and support educational environments. • Highly influential as an aid when integrated with BIM/CAD software. • Capacity to utilise as a training platform by simulation real construction environments.	• Limitations of hardware and software impacting the suitability for construction. • Existing parameters are impacting the uptake of technology and integration with current construction processes. • Time commitments and resources required to effectively introduce in the construction field.

Figure 5: Summary of results under the SWOT framework

The lack of due consideration about the practicality not only limits the prospect of broad applications but also the potential to understand the full extent of benefits. Notwithstanding, such phenomenon is not uncommon in other industries when the usefulness of a particular technology was being tested. Although the communication with CAD/BIM systems is currently of concern, successful examples of software development in both Apple IOS and Android has demonstrated that external competition may drive further improvements for the sake of the end-users.

6. CONCLUSIONS

6.1 The concluding remarks

To obtain a holistic view of the use of immersive technology in construction, a systematic review was conducted. The review study was backed by the SWOT analysis that helped display a complete understanding of the status quo of immersive technology implementation in the construction industry. A force field diagram in Figure 6 precisely represents the current state of immersive technology and its place in the construction field. Force field diagram is used because this can help demonstrate the imbalances of driving forces and restraining forces the influence change (University of Cambridge 2016).
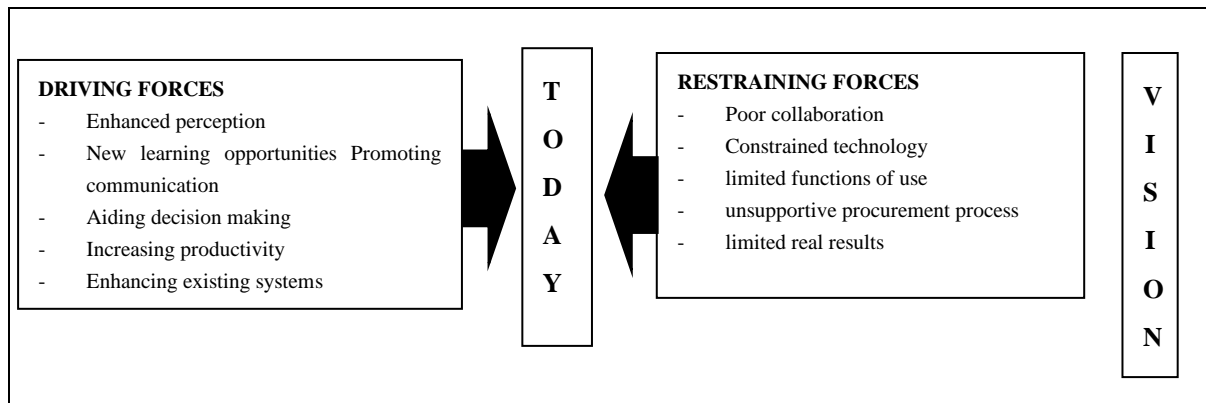

Figure 6: The status quo of immersive technology adoption in construction

In this context, the research to date has led us to where we are today. In particular, the rapid influx of research is the result of the opportunities known by many. This has been supported by the many benefits, whether they are perceived to be real or an opportunity at this stage. Nevertheless, these findings capture the aspects of the vision of immersive technology in the construction industry. What limits the vision being achieved is previous research findings that adopt an alternative perspective of technology underlining the void of many other articles. In particular, these viewpoints highlight some testing environments to be questionable whilst others acknowledge that the technology itself lacks the functions demanded by the construction industry. More specifically, software and hardware currently constrain more extensive and effective use of immersive technology in the construction projects. And slow software integration prevents the perceived benefits to be fully achieved and realised. This paper demonstrates that immersive technology will enhance existing systems including CAD and BIM tremendously; however, the process to integrate third party software is unknown.

Construction companies deserve to know that their investment is not one-off or piecemeal that fits only one contained goal. Investors must be convinced that their investment in immersive technology can be sustainable and is trending towards long term positive changes. For example, adoption of the technology is highly likely to be a game-changer for construction companies providing a leading edge over other companies. Alternatively, a succinct understanding of immersive technology and function, can generate new opportunities and businesses. Either way, long term planning is a key consideration with software procurement as ongoing benefits must exceed the initial investment. Subsequently, a comprehensive understanding of the technology is necessary to promote buyer confidence and eventually, a strong standing in construction applications.

6.2 Limitations and recommendations for further research

This analysis does have a series of limitations that must be considered. The main limitation of this paper is the constrained sample size of published journal articles and conference papers. The initial broad data search resulted in 156 papers; however, was significantly reduced to 88 highly relevant papers for the in-depth analysis. This article retrieval process did not restrict the location of papers, however, contained rigorous parameters including a published period of 1996 to 2020, and numerous keyword searches to determine applicable papers. In addition to this limitation, the process of analysing each paper selected involved reading each article and highlighting sentences or paragraphs relevant to the SWOT of immersive technology in construction. It must be noted that this task was subject to individual interpretation. To aid this process and ensure continuity across all papers analysed, key definitions and words were associated with each element of SWOT. Therefore, the findings of SWOT were

constrained simply to the strengths, weaknesses, opportunities and threats rather than the context of use. Findings of this study should be read with due caveat that only a systematic review was conducted. To verify and validate the results, qualitative approaches including interviewing relevant industry experts and focus group meetings are suggested.

The overarching themes highlighted from articles does demonstrate similarity and repetition in findings. Furthermore, an in-depth discussion of this paper provokes an emphasis on several key directions for future investigate. Prior to this, existing literature identifies the ongoing trend of construction-related papers conducting studies and simulations within a highly controlled environment such as a laboratory (Chalhoub & Ayer, 2018). It has been stated on multiple occasions by Goulding et al. (2012) and Shin and Dunstan (2008) that the research environment influences the effectiveness and relevancy of papers. Therefore, future studies are suggested to be conducted on-site or in an environment that closely simulations the various complexities of a construction environment.

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