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INTEGRATION STRATEGIES FOR ADVANCED CONSTRUCTION TECHNOLOGIES IN THE US AECO INDUSTRY

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SUMMARY: *Advanced Construction Technologies (ACTs) have fundamentally altered the way the US Architecture, Engineering, Construction, and Operations (AECO) industry operates. Over the past few decades, the US AECO industry has undergone a technological awakening, which promises to improve project quality and efficiency in a multitude of ways. The shift towards technology adoption began with Building Information Modeling (BIM), which for many years struggled to gain acceptance due to a largely ad-hoc integration strategy for organizations. As technologies continue to emerge and develop beyond, and in parallel with BIM, there are no tools available to help evaluate, plan and integrate such advancements in US AECO workflows. A series of semi-structured interviews were conducted with US AECO industry technology experts to establish a cursory list of the factors which impede or promote the successful integration of ACTs. These factors were evaluated, ranked and rated through a Delphi study, conducted with a panel of industry experts who at the time specialized or leveraged ACTs. A novel continuously iterative Delphi platform was deployed to gain the requisite expert input for the importance rating and impact ranking for each of the factors cited as influential in technology integration. The collected data was used to help bridge the identified gap between ACT development and successful integration of ACTs into US AECO industry workflows. Within the context of existing technology integration theories, this study identifies and evaluates factors which influence technological integration success within the US AECO industry. This study begins the process of establishing a foundation of understanding as it relates to meaningful ACT integration.*

KEYWORDS: *Advanced Construction Technology, Technology Integration, Delphi Analysis, US AECO Industry; Workflows.*

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1. INTRODUCTION

Over the past few decades the US Architecture, Engineering, Construction, and Operations (AECO) industry has undergone a fundamental shift toward technological advancement through the adoption of Building Information Modeling (BIM) and Virtual Design and Construction (VDC) technologies. In addition to individual company's internal integration strategies for BIM adoption, more governments are also beginning to mandate BIM use thus forcing the US AECO industry to undergo a technological awakening. The integration process that BIM has undergone, and is continuing to undergo, has laid the groundwork for other advanced construction technologies (ACTs) which promise to revolutionize the US AECO industry. For the purpose of this study, ACT is defined as; *a novel information technology which provides either a more efficient means of collecting, accessing or distributing data, or an original data stream which has the potential to add efficiency or provide value to a US AECO project*. BIM, reality capture, and Unmanned Aerial System (UASs) are examples of existing ACTs within the context of this study.

For over a decade the integration of BIM technology has been underway in the United States and around the world. The introduction of the first BIM project execution planning guide provided a framework to help companies and governments develop and integrate BIM strategies into their workflows (CIC 2011). Unfortunately, this plan only helped with the integration of core BIM technology, but did not help with the integration of other ACTs that are continuously being developed and becoming available to project teams.

The integration of ACTs in US AECO workflows differs greatly from BIM due to the fact that each ACT provides a specific set of advantages or data streams that can but do not necessarily have to be part of the BIM process. In addition to the potential BIM process impact, companies must consider multiple other factors, both internal and external, prior to deciding to integrate an ACT into their workflows. Some of the many considerations which can impact the integration of new technology include a company's readiness to use technology; availability of expertise; capabilities of subcontractors; required capital investment; effort investment; and gaps in organizational knowledge.

The goal of this research is to determine and evaluate specific factors involved in achieving meaningful ACT integration in the US AECO industry. To this end, semi-structured interviews were conducted with US VDC and AECO professionals. The data gathered during these interviews were used in the development and execution of a Delphi study, hosted on a novel continuously iterative online platform, intended to establish the major factors which promoted or impeded the integration of ACTs. This study provides foundational insight into the practical integration of ACTs within the US AECO industry with the intention of informing and spurring further study.

2. LITERATURE REVIEW

The innovation and adoption of novel technologies in the US AECO industry has been a focus of forward-thinking practitioners and researchers, especially in the past few decades. Many researchers have sought to better understand the underlying concepts which drive both the innovation and diffusion of technology within an organization as well as for individuals. This branch of scientific inquiry is certainly not unique to the US AECO industry but has become somewhat of a focus since the advent of BIM, and as the industry reaches a technological tipping point. The manner in which technology is developed and adopted can be viewed from multiple perspectives, each providing unique insight into the complex environment surround ACTs in the AECO industry. Furthermore, a number of strategies exist which try to quantify and categorize the way technology is developed, evaluated and diffused within any industry. In order to fully comprehend the process of technological integration, which is anything but simple, it is crucial to understand not only how technologies are developed or defined, but also the prevailing innovation and adoption strategies which drive this field of study.

2.1 Innovation Theory

The US AECO industry is often categorized as a lagging producer and consumer of innovation when compared to other industries. This is largely attributed to the fact that the US AECO industry tends to be primarily driven by cost when making decisions. Identifying the specific economic advantages to innovation, as well as who would be the primary beneficiary of any savings, is seen as a driving factor which influences innovation industry wide (Macomber 2003). However, other work (Ozorhon, et al. 2014) has found that there are factors which can encourage and in some ways embolden a company to work towards technological innovation.

Gambatese and Hallowell (2011) sought to determine and evaluate the major factors which influenced the initiation, development and diffusion of technological innovation in the construction industry. The primary enabling factors for innovation, rated as significant or higher by the respondents on a Likert scale, were; owner/client support (80%), organizational culture (79%), presence of an innovation champion within the firm (76%) and communication among the project team (71%). The major barriers were reported as: fear of change (53%), lack of communication (24%) and lack of client recognition for the value of innovation (35%) (Gambatese and Hallowell 2011). Based on these results it was suggested that increased innovation and diffusion could be realized through increases in communication, encouragement from upper management for teams to try new things, and formal innovation meetings. As the industry continues to globalize, in an increasingly digital world, many of these barriers will fade away and the focus will shift from the innovation itself, largely done by private sector companies and academics (Son et al. 2010), to the diffusion of such technology into daily workflows.

2.2 Prevailing Technology Innovation and Adoption Strategies

There exist a number of technological innovation and adoption strategies which have been developed and studied since the end of the 20th century. Six of these pervading strategies and theories which dominate the literature related to technology acceptance and adoption success modeling and provide context to this work include: Innovation Diffusion Theory; Technology Acceptance Model (TAM); United Theory of Acceptance and Use of Technology (UTAUT); Theory of Planned Behavior; Technology, Organization and Environment Context (TOE); and Technology Transfer (T^2). In addition to the prevailing technology innovation and adoption strategies, it is also prudent to consider the basic psychological foundations which many rely on. Rudimentary understanding of these theories provides context to the goals of influential factor identification and review in this study which lays the groundwork for the development of practical strategies to improve ACT integration success.

2.2.1 Innovation diffusion theory

The seminal work on the diffusion of innovations was authored in 1962 by Rogers (2003), who studied how technology spreads through cultures focusing on four main elements: the innovation itself, communication, time, and contextual social systems. His categorization of adoption groups is widely used by technology industry practitioners and groups individuals in the categories: innovators, early adopters, early majority, late majority and laggards. This categorization is relied upon or expanded upon in many of the theories discussed here.

2.2.3 Technology Acceptance Model (TAM)

The most accepted theory and technology innovation and adoption strategy is the Technology Acceptance Model (TAM), which was developed to help improve the understanding of acceptance processes and offer a practical user acceptance testing methodology for use by technology innovators and companies hoping to evaluate potential success (Davis 1986). The TAM is focused on the concept that a user's attitude towards a certain technology is a driving factor as to whether or not it will be actually used. The user's attitude is shaped by the perceived usefulness and ease of use for a certain technology (Davis 1986). TAM is applicable to the US AECO industry in that it seeks to evaluate the potential for success of technological adoption at the individual level through two main variables: perceived usefulness and ease of use. To this end, TAM has been used for a variety of topics ranging from Smart Construction System success to BIM acceptance (Lee et al. 2003; Lee et al. 2015; Liu et al 2015).

2.2.3 United Theory of Acceptance and Use of Technology (UTAUT)

The United Theory of Acceptance and Use of Technology (UTAUT) is the product of an evaluation of pervading acceptance models which have been combined to produce what the authors consider a unified theory. Four major factors are used in UTAUT: performance expectancy; effort expectancy; social influence; and facilitating conditions (Venkatesh et al. 2003). The UTAUT model was empirically tested to determine the validity of its combined mathematical modelling using factors and reasoning from previous theories (Venkatesh et al. 2003). The UTAUT model provides a set of factors which are used as the determinate parts of a technology's integration.

2.2.4 Theory of Planned Behavior (TPB)

The Theory of Planned Behavior (TPB) is based on the principle that all actions are controlled by intentions combined with the study of the relationship found between action and intention (Ajzen 1985). The TPB takes into account an individual's attitude toward a behavior, perceived control of that behavior, and the perceived social pressure surrounding a behavior, labeled the subjective norm (Ajzen 1991). Every action taken on a construction site is aimed at the goal of completing the construction. In this regard, the intentions of the workforce are generally known and thus any change to the resources or conditions they are presented with will arguably alter the action taken which gets them to that goal. In the context of the US AECO industry, this concept can apply to every aspect and not just technology-based decisions.

2.2.5 Technology, Organization and Environment Context (TOE)

The Technology, Organization and Environment Context (TOE) theory establishes technological decision making in the context of three separate aspects, organizational, technological, and environmental, which have the ability to influence technology adoption decisions (Oliveira and Martins 2011). These three contexts take the basic principles outlined by Rogers (2003) in the innovation diffusion theory and add the environmental context to the potentially influential factors (Oliveira and Martins 2011). Understanding the factors which influence the operation of an organization is crucial to effective technological decision making.

Due to the inclusion of the environmental context, not found in the innovation diffusion theory, some researchers find TOE to be a more effective means of explaining how innovation adoption occurs within an organization (Oliveira and Martins 2011). The nature of the BIM process, and many data-based ACTs, is that they are a collaborative endeavor which requires input and involvement from multiple project stakeholders beyond the contractor's project team. Due to this, the TOE theory offers a potential way to consider the impact that such external influences could have on the adoption of innovations within an organization. The context within which an innovation is intended to be integrated is a crucial component towards the proper evaluation of its potential success. This concept is directly applicable to the US AECO industry which is inherently interconnected and increasingly relies on the collaboration and cohesiveness of a range of project participants as the use of technology continues to grow.

2.2.6 Technology Transfer (T^2)

Technology Transfer (T^2) is a strategy for technological dissemination and integration which focusses on how information and processes are shared within an organization (Hood et al. 2014). T^2 involves at least two parties the source and the recipient. In some situations, a third party can be involved that facilitates and initiates the information sharing between the source and recipient (Hood et al. 2014). T^2 is a process which is intended to be directed at solving a problem, or gaining an advantage, while also being able to handle more subtle evolution within an organization (Hood et. al. 2014). T^2 was developed as a guide to aid heavy highway organizations in the transfer of information and subsequent dissemination of information, processes, or technical knowledge. Its conceptual frameworks outline universal considerations for technological integration broadly applicable to the US AECO industry, as the dissemination of information and process knowledge is a constant need in every segment.

2.2.7 Foundational Psychological Theories

Two of the primary base psychological theories which impact much of the work on adoption strategy and evaluation studies are the Theory of Reasoned Action (TRA) and Social Cognitive Theory (SCT) (Bandura 1986, Sheppard et al. 1988, Venkatesh et al. 2003). TRA is focused on the individual's perception towards performing a given action based on their feelings about it, in addition to how those people deemed important to them felt about such an action, known as goal intentions (Sheppard et al. 1988). SCT is focused on the individual's perception of the perceived consequences, both personal and performance based, of a specific action and how they personally feel about performing the behavior itself (Venkatesh et al 2003).

Cao et al. (2014) found that internal and external factors exerting influence on technology adoption has extended beyond CAD to BIM in the modern industry. These concepts are categorized as isomorphic pressures and include mimetic, normative, and coercive pressures which each have unique characteristics (Cao et al. 2014). Fundamentally, in context, mimetic and normative pressures are often those applied internally to maintain an appearance of legitimacy, coercive pressures are those imposed on an organization by another, i.e., government mandates or regulations (Cao et al. 2014). This scientific classification of influential factors offers meaningful insight into the way technological adoption is viewed in the industry today.

The consideration of these base theories provides context to the discussion of technological adoption at a psychological level and influences the acceptance models related to technological acceptance and adoption strategies which are frequently cited. When considering technological adoption, it is crucial to remember that human factors must be evaluated simultaneously with the technology and processes.

2.3 Communication and Data Collection Techniques

There are a wide range of methodologies to choose from for the collection of data related to technology adoption and policy opinions. The complex issue of ACT integration in the AECO industry is not one that can be studied in a strictly quantitative fashion and as such requires the use of qualitative research methodologies. Traditional surveys, interviews, panel discussion and Delphi studies are a few of the relevant and prevailing methods available for this kind of research. Each have inherent advantages and disadvantages and must be careful considered prior to making a selection. Our research relied on semi-structured interviews and a Delphi study to foster a deep understanding of the problem at hand while producing the most useful data set for analysis and utilization, based on the expertise of industry professionals. The selected methods will be briefly outlined in this portion of the literature review, along with the reasoning for their selection in this study.

2.3.1 Semi-Structured Interviews

Interviews, which are one of the most common knowledge producing methods used in the human and social sciences, are also an effective methodology for AECO research. Interviews are best suited for situations when key experts or people can be identified who understand the topic in question well enough to offer valuable insight. This form of research can be preferable to a questionnaire because the number of respondents sought is smaller, the level of detail in responses is greater and the collection of responses is ensured as it is completed live and in person (Rowley 2012).

Semi-structured interviews, which fall in between the extremes of a formal questionnaire and an unstructured conversation, make use of a predetermined guide with questions for topics which must be covered, and are commonly used in policy research. This technique is intended to afford the researcher the opportunity to delve deeply into a topic and understand thoroughly the answers provided by the interviewee, whilst ensuring that the intended subject matter is addressed (Harrell and Bradley 2009).

2.3.2 Delphi Studies

The Delphi technique was developed in the 1950s by the RAND corporation as part of a United States Air Force project to determine an expert opinion for a variety of national security issues (Linstone and Turoff 1975). It was not until the 1960s that the technique found uses outside of the military and began to demonstrate scientific promise to the academic community. The Delphi technique today, has become a tool which is used for a range of studies across the world and offers a unique way to gather insight to complex issues (Skulmoski et al. 2007). Researchers in the AECO industry have validated the use of Delphi studies and have used Delphi techniques for a range of topics including the assessment of owner BIM competencies and non-geometric building information needs assessment for facilities management (Giel and Issa 2015; Hallowell and Gambatese 2010; Mayo and Issa 2016). The Delphi technique is best suited as a research instrument when there is incomplete knowledge about a problem or phenomenon, especially when the overall goal is to improve understanding of problems, and experts on the topic provide the best source of information (Skulmoski et al. 2007).

The policy Delphi, first introduced in 1969 as a departure from the traditional forecasting Delphi technique, at its core is an organized method for the correlation of views and information related to a specific policy topic, while affording respondents the opportunity to assess and critique differing viewpoints anonymously (Linstone and Turoff 1975). In this regard, the Policy Delphi technique offers advantages over traditional panel or committee processes. For example, it keeps one domineering personality from monopolizing the process, eliminates the fear of public disagreement with superiors, and reduces ones unwillingness to abandon a publically stated task. Most importantly, the provided anonymity allows participants the freedom to fully express ideas and discuss alternatives without the fear of judgement or repercussions (Linstone and Turoff 1975).

While a traditional forecasting Delphi relies on experts in a given topic area, the policy Delphi is based on the underlying understanding that there are no definitive “experts”, only informed advocates and referees for a given topic. In this sense the goal is not necessarily to reach a consensus among a homogenous group of experts but rather to generate a debate over the potential resolutions to a policy issue. Each participant contributes reasoning and beliefs surrounding a particular resolution but is unlikely to develop a clear and universally consensual resolution to the policy in question. The researcher, in this form of Delphi, is not looking for the group to generate a decision, but rather to have an informed group present all the options and supporting evidence for consideration (Linstone and Turoff 1975). The policy Delphi is an effective tool for the evaluation of an issue that does not attempt to come to a decision or reach a consensus. The traditional Delphi technique aims to develop a consensus and make decisions while the primary objective of a policy Delphi is information discovery and debate.

3. RESEARCH METHODOLOGY

This research consisted of two phases: semi-structured industry interviews and a Delphi panel. The selected industry practitioners were relied upon to determine not only the existing state of integration, but also to identify the factors that impeded or promoted the effective integration of various technologies. They were selected based on their role in the industry at the time of the study, with a focus on those who were directly working with or managing construction technologies in some way in their existing role. Both phases of this study and the industry participation received University of Florida Institutional Review Board (IRB) approval prior to commencing.

In developing the sample size and participant pool the primary focus was placed on professional expertise and technological utilization. Accordingly, three US demographic groups from within the construction industry were selected for the purpose of providing informed insight from those: (1) who make decisions focused on construction technologies (VDC professionals in management and director roles); (2) who work to institute such decisions (VDC/BIM professionals): and (3) whose daily work is impacted by such technology integrations (project or field personnel). After identifying the type of industry professionals sought, the next step was to evaluate the geographical and industry segment representation in the potential participant group.

The US AECO industry is notably diverse in company size, organizational philosophy, project types, and areas of operation. This industry diversity when matched with a realistic scope for this study required the researchers to refine the participant pool to a point with which cursory findings could be uncovered, while focusing primarily on the aforementioned expertise of the participants themselves. To this end, the participant pool for this research came exclusively from the large commercial segment of the US AECO market with a variety of company sizes.

The decision was made to maintain a participant pool exclusively from one corridor of the United States because the East, Central, and West portions of the country represent different levels of market density, technological utilization, and project diversity. Specifically related to technology and based on conversation with industry experts, the epicenter of technological advancement found on the West coast creates a much different mindset as it relates to the integration of technology. This could skew data and make reconciliation among participants based on professional context difficult. Furthermore, project and geographical diversity and density on the East coast presented the opportunity to conduct this initial study with professionals that have experience in multiple climates with varied types of projects. The findings of this study, reviewed within the context of the participant pool, can be later expanded and focused on additional areas of the US AECO industry that have some of the unique geographical or technological influences mentioned here.

Based on the availability of industry experts, study participants were selected from those who met the selected expertise, geographical, and market criteria. A letter was sent to each study participant requesting a formal interview to confirm their willingness to be involved in this research. The letter provided a brief explanation of the overall research goals as well as the anticipated level of commitment required. Research has indicated that a minimum of eight panelists is generally recommended for a Delphi study with focus being placed on expertise, intended outcomes, and an understanding that some participants will not complete the study (Hallowell and Gambatese 2010). To this end, thirteen participants were gathered to complete the semi-structured interviews, and eleven continued to complete the Delphi study.

3.1 Semi-Structured Interviews

Every interview began with the researcher providing a definition of the term ACT and outlining the goals of this research, including the interview and the Delphi phases, as well as how their involvement would benefit the overall quality and outcome of the proposed work. The semi-structured interview was conducted by utilizing a series of prompts which help guide the conversation while affording the interviewee the opportunity to speak in as much depth, or with as much brevity, as they desired on a given topic. Furthermore, the series of prompts did not need to be addressed in any given order, thus allowing the interview to progress more naturally as a normal conversation would. The prompts for this research were developed to guide the conversation through the experiences and beliefs of the interviewee, culminating in the defining of specific factors which the interviewee could cite which either promote or impede the successful integration of ACTs into US AECO workflows. An interview report was generated at the end to summarize the opinions of each interviewee in a uniform manner for later comparison.

The interview structure encouraged the interviewees to explore the topic at hand in their own way while sharing opinions founded on their experiences. Based on the thoroughness of the participants responses, the quantity of the data/salient factors collected, and the thoughtfulness of responses achieved the use of semi-structured interviews proved adequate for the collection of data related to the integration of ACTs within the US AECO industry. The findings of the interviews were further evaluated and refined through the completion of a Delphi study in the second phase of this research.

3.2 Delphi Study

The second phase of this study involved a Delphi panel composed of participants solicited and selected during the preceding interview phase. A web-based Delphi Management System (DMS) application was developed that took the concepts of a policy Delphi (Rayens 2000) and a real-time Delphi (Linstone and Turoff 1975) and expanded them to be a live and continuous process which provided the participants with an accurate data rich environment upon which to base their decisions and adjustments. The DMS was used for the completion of the continuously iterative Delphi conducted in this study. Figure 1 through Figure 4 depict the various pages of the DMS interface which was developed for the purposes of this study.

Figure 1: DMS Login

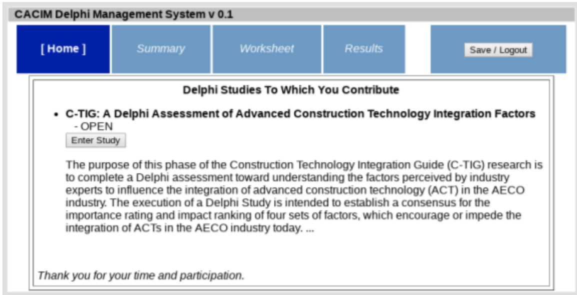

Figure 2: DMS Study Home Page

Figure 3: DMS Study Summary Page

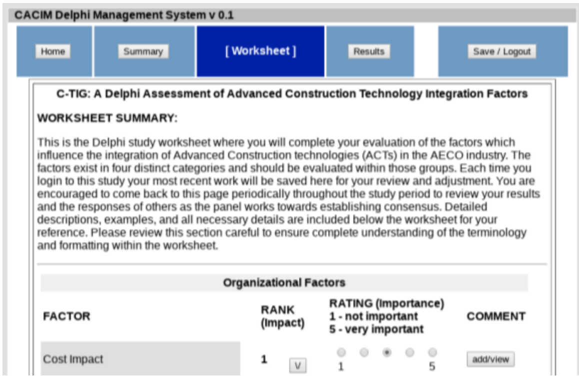

Figure 4: DMS Worksheet Interface

3.2.1 Delphi consensus calculations

Gracht (2012) conducted a review of Delphi consensus measurement and identified 15 unique consensus measurement techniques in leading research which made use of the Delphi technique. Given that a Likert scale rating and grouped ranking are vastly different evaluation models, it was necessary to calculate consensus in a different way for each of them. The methodologies used for this study were largely based upon the previous work of researchers evaluating technology use in the US AECO Industry (Giel and Issa 2015, Mayo and Issa 2016). The Likert scale *Importance Ratings* were evaluated on an independent factor basis using a combination of Inter Quartile Range (IQR) and agreement percentage calculations. *Impact Rankings* were evaluated using Kendall's Coefficient of Concordance (W), in combination with the chi-square approximation to establish confidence (Kendall and Gibbons 1990).

Rayens and Hahn (2000) reported that an IQR of 1 or less, on a 4-5 point Likert scale, was a reasonable level for the evaluation of consensus and recommended that a form of agreement percentage should also be considered depending on the level of confidence desired. Table 1 shows the established levels of consensus for importance ratings, ranging from *Consensus* to *Split Disagreement*, as well as the IQR and agreement percentage levels for each. A final achieved consensus level for each factor was selected by comparing its IQR and agreement percentage levels. For example, if a factor had ratings with an IQR of 0.8 and 70% of the respondents selected the same ranking, then that factor would have achieved *Consensus*. An agreement percentage level of two-thirds was utilized in this study as it is an established level of agreement used commonly in political voting scenarios and provides a reasonable assumption of agreement among a group (Gracht 2012). Using the defined agreement scale, one unique level of consensus is the *Split Disagreement* category. This category indicates that a factor not only has a large IQR, and thus widely distributed results, but also that the ratings were collected at either end of the Likert scale.

Table 1: Importance Rating consensus levels

Level of Consensus	IQR Range	Agreement Percentage
Consensus	0 – 1	≥ 67% *(on a single level)*
Strong agreement	0 – 1	≥ 67% *(on any 2 adjacent levels)*
Partial agreement	1 – 2	≥ 67% *(on any 2 adjacent levels)*
Disagreement	> 2	< 67% *(on any 2 adjacent levels)*
Split-disagreement	> 2	≥ 67% *(on 2 extremes, i.e. 1 and 5)*

Five levels of consensus were used for the *Importance Rating* and four for the *Impact Ranking* due to the different nature of its calculation. While the *Importance Rating* consensus level was calculated independently for each of the established integration factors, the *Impact Ranking* was calculated based on the four established integration factor groupings used with the defined categories shown in Table 1. In addition to the raw calculations, the DMS leveraged color coding to aid the participants' comprehension of the consensus levels as they interacted with the study.

In this study, Kendall's W was used to determine the level of concordance for the *Impact Rank* of each of the four established factor groupings. In this manner, the rankings of the factors within the groupings could be evaluated for agreement. Table 2 shows the four levels of consensus established for the *Impact Ranking* portion of this study. The initial categorization of consensus occurs based on the calculated *W* value and then the confidence level is applied to determine final ranking. In this way, a factor grouping must achieve a confidence level of greater than 99%, based on the chi-square approximation and significance table, in order to be able to achieve consensus regardless of its W value. If the confidence in a factor grouping is less than 95% then the group cannot achieve greater than partial agreement, due to the possibility that random chance could be producing the reported rankings. Similar to the *Importance Rankings*, using a two-step consensus calculation process ensured robustness in the conclusions drawn and provided the best information to the expert panelists as they worked through the Delphi study. While the levels of consensus calculated provided great insight to the panelists and during the formulation of conclusions, they were not used to determine the length or conclusion of the Delphi period.

Table 2: Impact ranking consensus levels

Level of Consensus	Kendall's W	Confidence Level *(Chi²)*
Consensus	0.75 – 1.0	≥ 99% Confidence
Strong agreement	0.5 – 0.74	≥ 95% Confidence
Partial agreement	0.25 – 0.49	
Disagreement	< 0.25	

The combination of *Importance Rating* and Impact Ranking methodologies offered a unique perspective of factors which potentially influence the integration of ACTs into US AECO industry workflows. Furthermore, the combination of evaluation methodologies, enabled through the novel DMS platform, resulted in a Delphi process which provided meaningful outcomes for both the ACT data, as well as the process by which such data can be re-evaluated moving forward.

4. RESULTS AND ANALYSIS

4.1 Semi-Structured Interviews

The interview stage of this research was conducted over a period of three months, culminating in over ten hours of raw, recorded interview data, collected from thirteen industry experts. Each industry expert was given the opportunity for the interview to be conducted in-person or via videoconferencing. The in-person interviews ran, on average, 9.3 minutes longer than the videoconferencing interviews, with the two longest interviews taking one hour each. Additionally, all 13 interviewees initially agreed to participate in the subsequent Delphi study, with only one formally recusing themselves at a later date due to time constraints.

A total of 91 technology integration factors were cited by interviewees as either promoting or impeding the integration of ACTs into AECO industry workflows. These factors were consolidated based on identifying those which were semantically different but intended in the same way. This consolidation brought the total number of individual factors down to 46, a nearly 50% reduction in the number of factors. Twenty-Four factors were unique and were unable to be consolidated, and thus remained independent. In addition to consolidation the individual factor names were adjusted to increase comprehensibility and increase the ability for common understanding in the subsequent Delphi phase.

As shown in Table 3, four distinct factor groupings were developed for analysis: *Organizational Factors*, which impact the integration of technology at the corporate or company level; *Personnel Factors*, related to the individuals and their relationship involved in the process of technological integration; *Technology Factors*, based on the technology itself which is being considered for integration; and Implementation/Performance Factors, related to the integration process, its execution and the associated support. The definitions for each factor, based on the intended meaning gleaned from the interviews, were shared with the Delphi study participants to ensure that each participant evaluated factors based on a common understanding.

Table 3: Delphi factor grouping and individual descriptions (# of citations shown next to factor)

Organizational factors (n=12)	
1. Inclusion in Budget *(4)*	Cost of the technology is considered during project budgeting
2. Clear & Direct User Benefit *(2)*	Use of the technology has an easily identifiable benefit to the user
3. Client Engagement *(1)*	Client interested in the technology being used and gets involved in the process
4. Contract Delivery Method *(1)*	Contract type used for a project impacts the ability to leverage technology
5. Contractual Requirement *(2)*	Owner requires specific technology to be used via the contract
6. Cost Impact *(6)*	Cost of the technology and its operation is considered independently of its ability to be considered in budget
7. Goal & Purpose Development *(2)*	End goal and “Why” is clear and shared with personnel
8. Measurable Outcomes *(2)*	Metrics are put in place to evaluate the performance impact of a specific technology, with the results able to be shared
9. Organizational Tech Evaluation Speed *(1)*	Time it takes for an organization to review, approve, acquire, and implement a new technology
10. R&D Time and Resources *(1)*	Ability of the organization to dedicate and spend time and resources researching new technologies for use
11. Managing Expectations *(4)*	Realistic and clear expectations are set for the use and expected outcomes of a specific technology
12. ROI *(0)*	Projected return on investment of a given technology
Personnel Factors (n=11)	
13. Appropriate Personnel *(3)*	Employees with the specific set of skills and willingness to learn exists to utilize the specific technology
14. Availability of Personnel *(1)*	Existence of an appropriate number of personnel to manage new technology and/or its integration

15. Field/Project Team Buy-In *(3)*	Project/field team members understand purpose of new technology and want to include it in their workflows, or are at least willing to try
16. Forward Thinking Mentality (Future Benefit) *(1)*	Ability of personnel to see a new path forward in implementing technology for their project workflows
17. Leadership/Upper Management Buy-In *(4)*	Executive team sees value or potential in tech and wants its integration within the organization
18. Learning Curve *(2)*	Amount of time it takes personnel to get up to speed with a new technology process and past initial slow downs
19. Loss of Trust *(1)*	Bad experiences with technology in general or with specific technology
20. Peoples' Resistance to Change *(4)*	Existence of personnel who do not see value in changing or are unwilling to change existing workflows
21. Previous Experience/ Use Case *(3)*	Availability of use cases or sharing of personal experiences related to a specific technology to demonstrate the potential impact it may have
22. Project Leadership Mentality *(1)*	Does project manager/executive find value in tech integration
23. Tech Savviness of Project Team *(3)*	Technological capabilities of the project team as a whole, who will have to use the new technology or its data
Technology Factors (n=11)	
24. Appropriate Tech Selection *(5)*	Right technology for the right job
25. Appropriateness of Tech to End-User *(1)*	Technologies ability to relate to the end user and their needs
26. Cloud Readiness *(1)*	Can the data be stored/accessed or the technology itself be accessed via a cloud solution?
27. Limitations of Selected Tech *(1)*	Limitations in the capabilities of the technology itself
28. Mobile Readiness *(1)*	Accessibility of technology or its data from mobile platforms such as tablets or cell phones
29. Quality of Technology *(1)*	Overall performance or appearance of the technology related to its promised capabilities
30. Abundance of Technological Options *(1)*	Quantity of options available from a range of companies for a specific technology or solution
31. Real-Time Data Access *(1)*	Does the data update live, does it need to sync, and do field teams have access to up-to-date data?
32. Support from Tech Developers *(1)*	Amount of assistance provided from the makers of the technology, training, tech support, etc.
33. Technological Change & Development *(1)*	Speed with which technology changes or updates
34. Usability of Technology *(2)*	User friendliness of the technology itself
Implementation/Performance Factors (n=12)	
35. Implementation Flexibility *(2)*	Ad-hoc project to project use and alternative solutions for project teams
36. Availability of Best Practices *(1)*	Examples available from past projects or industry experiences
37. Communication *(5)*	Expected users of the technology are provided all relevant information related to the technologies use and goals
38. Comprehensiveness of New Tech Introduction *(1)*	Presentation method for new technology exposure and thoroughness with which it provides the requisite information
39. Demeanor of Implementation Professional *(1)*	Attitude and personality of the person in charge of integration and outreach for a specific technology
40. Inclusion of Users in Solution Development *(1)*	Are the end users included in the development of a tech-driven solution they will be expected to use?

41.	Incremental/Phased Integration *(2)*	Staged or phased rollouts of technology, not all at once
42.	Result Driven Selection *(1)*	Technology was selected for its benefits or potential and not for more superficial reasons
43.	Planning *(3)*	Plan is in place for how the technology will be rolled out, integrated and supported
44.	Project Team Champion *(1)*	Subject matter expert available or is trained on individual projects utilizing the specific technology
45.	Proximity of Support Team *(1)*	Geographical proximity of the person(s) who will support the technologies and provide user support
46.	Training *(4)*	Effective training is provided to support those with a lack of knowledge needed for the operation and use of a new technology

Basic statistical data for each of the ACT integration categories was compiled for further analysis (Table 4) with the goal of gaining cursory insight into the data which informed the subsequent Delphi phase. The initial results found during the consolidation and grouping of integration factors show that the *Organizational* and *Personnel* factor groups achieved the highest rates of factor citation with an average of 1.92 and 2.36 citations per factor respectively. The *Technology* factor group received the lowest average citation rate per factor at 1.54. These findings indicate that the *Organizational* and *Personnel* factor groups have a greater level of initial agreement toward factor identification, while the *Technology* and *Implementation/Performance* factor groups may be more individualized based on experiences. Each factor grouping had at least one factor cited four or more times, with the highest single factor citation rate being 6, in the *Organizational* factor group. Interestingly, the *Personnel* factor group had the lowest individual factor citation count, the highest average citation rate, and the lowest single factor citation rate. This indicates an even distribution of citation rates among the entire group.

Table 4: ACT integration factor groups statistics

Factor group	Average citations	Number of factors	Number of single citations	Ind. Factor Citation Count
Organizational	1.92	12	4	**6**
Personnel	**2.36**	11	4	4
Technology	1.54	11	**8**	5
Implementation/Performance	1.75	12	7	5

Overall the influential integration factor analysis conducted following the interviews provided valuable information which directly informed the development of the Delphi study. Furthermore, the preliminary analysis provided insight into potential trends which might exist related to ACT integration. Preliminary analysis showed that the integration factors related to *Organizational* or *Personnel* factor group were more frequently cited, on average, than those related to *Technology* or *Implementation/Performance* group. This finding provides a basis for the belief that personal experience related to technology or its integration can lead to a diverse set of beliefs as to what garners success. Furthermore, the analysis conducted based on the interviews overwhelmingly supported the need for planning, goal development, and clarity during the ACT integration process. These initial findings were of great interest and required further study during the Delphi phase to achieve greater levels of confidence in the potential impact of these factors.

4.2 Delphi Study

The Delphi study phase of this research was conducted over a period of two months and proceeded in two distinct stages. The continuously iterative style of the Delphi study used was executed using the Delphi Management System (DMS), and as such did not take place using the traditional one round at a time completion style. The first stage was the initial response period, and was followed by the iterative response period. Each stage was open for approximately one month and was conducted entirely through the automated DMS platform. Thirteen expert panelists agreed to participate in the Delphi phase and completed the Delphi study.

The initial response period of the Delphi study was released to the panelists and reminder emails were sent weekly to spur involvement. This time was provided to afford expert panelists the opportunity to complete the impact rankings and importance ratings for each factor without being swayed initially by others input. During the initial response period, eight out of thirteen of the expert panelists who agreed to participate completed the Delphi study. All eight provided importance ratings for each factor, while five out of the eight provided impact ranking evaluations. This represented an initial response rate of 61.5% and 38.5% respectively. Those who did not complete the initial stages were contacted for completion prior to their receiving access to the "results" page of the DMS unlocked during the iterative response period. This lead directly to the increase in participation to 11 by the end of the iterative response period.

The iterative response period of the Delphi study took place over the course of one month and allowed the expert panelists to review the cumulative results, assess consensus levels, provide comments, and adjust or defend their responses. At the conclusion of this response period a total of 11 expert panelists had provided complete importance rankings and eight had provided complete impact rankings. This represented an 84.6% importance rating response rate and a 61.5% impact ranking response rate based on the 13 panelists who agreed to participate initially. Throughout the entire Delphi study period a total of 1,800 individual interactions with their worksheet were recorded through the DMS among the expert panelists. The maximum number of individual worksheet sessions was eight with a minimum of three.

4.2.1 Initial Response Data

The initial response period of the Delphi phase of this study was the panelist's first opportunity to interact with the DMS and the topic of technological integration in the context of this research. The initial response period participant interaction data, collected though the DMS, indicated that panelists frequently provided importance ratings first, with the impact rankings being addressed either second or at a later date. The data from the initial response period provided a baseline from which to compare progress during the iterative response stage of the Delphi study.

The initial responses for this study yielded low levels of consensus for almost every category and factor grouping, in both the importance rating and impact ranking. The measure of consensus is not an indication of the factors impact rank or importance rating but is rather an indication of the level of agreement between the expert panel on the individual factor rank or rating. It is important not to confuse consensus, or level of agreement, with actual establishment of impact rankings and importance ratings for the factors. The data for all the ACT integration factors based on both the initial and final response period results are shown in Table 5 - 8, ordered based on the mean *Importance Rate* at the time of final response period completion.

Table 5: Delphi initial and final response data for Organizational factors

ACT integration factor	Initial Response Data (*impact n=5, importance n=8*)			Final Response Data (*impact n=8, importance n=11*)		
	Mean Impact Rank	Mean Importance Rate	IQR	Mean Impact Rank	Mean Importance Rate	IQR
Clear and Direct Benefit to User	1.6	4.75	0.25	1.625	4.82	0.00
Measurable Outcomes	7.4	4	0.50	7.25	3.91	1.00
ROI	6.8	3.875	1.25	5.875	3.91	0.50
Cost Impact	5	3.875	2.00	6.25	3.73	1.00
Client Engagement	6.2	3.5	1.00	4.75	3.73	1.50
Managing Expectations	7.8	3.625	1.25	8.625	3.64	1.50
Goal and Purpose Development	5.6	3.375	1.25	4.75	3.55	1.00
Contractual Requirement	3.8	3.5	1.25	5.625	3.09	1.50
Contract Delivery Method	8.8	2.75	0.25	8.125	3.00	1.50
Inclusion in Budget	7	3.125	2.00	6	2.82	1.50
Organizational Tech. Eval. Speed	9.6	3.125	0.00	9.625	2.73	1.00
R&D Time and Resources	8.4	3.125	2.00	9.5	2.73	1.50

The *Impact Rankings* were evaluated for consensus based on the ACT integration factor groups using Kendall's W and Chi square analysis. Based on those calculations three of the groups achieved partial agreement with one group achieving strong agreement. Table 9 shows the calculated values for each factor grouping at the close of the initial response period. The p-value was calculated for each of the groups, based on the Chi squared value, and showed that three of the factor groups yielded 95% confidence in the results and were significant. The fourth factor group, *Integration/Performance, proved* non-significant with only 83% confidence in the results. The independent *Importance Ratings* showed varied levels of agreement based on the Table 1 which are based upon the calculation of the Inter-Quartile Range (IQR) and agreement percentage.

Table 6: Delphi initial and final response data for Personnel factors

ACT integration factor	Initial Response Data *(impact n=5, importance n=8)*			Final Response Data *(impact n=8, importance n=11)*		
	Mean Impact Rank	Mean Importance Rate	IQR	Mean Impact Rank	Mean Importance Rate	IQR
Field/Project Team Buy-In	3.6	3.875	2.00	3	4.36	1.00
Leadership/Upper Management Buy-In	3.4	3.875	2.00	3.875	4.09	2.00
Project Leadership Mentality	8.6	4.125	1.25	8.125	3.91	2.00
Availability of Personnel	4.2	3.75	1.25	3.875	3.91	1.00
Appropriate Personnel	3.8	3.375	1.50	3.5	3.91	2.00
Peoples' Resistance to Change	7	3.75	1.25	7.625	3.73	1.50
Forward Thinking Mentality (Future Benefit)	5.8	3.25	2.00	6	3.55	1.00
Loss of Trust	6.2	3.375	1.00	6	3.55	1.00
Learning Curve	5.2	3.625	1.00	5.875	3.36	1.00
Tech Savviness of Project Team	11	3.125	1.25	9.375	3.45	1.00
Previous Experiences or Use Case	7.2	3.625	2.25	8.75	3.27	1.50

Table 7: Delphi initial and final response data for Technology factors

ACT integration factor	Initial response data *(impact n=5, importance n=8)*			Final response data *(impact n=8, importance n=11)*		
	Mean Impact Rank	Mean Importance Rate	IQR	Mean Impact Rank	Mean Importance Rate	IQR
Appropriateness of Tech to End-User	3.8	3.625	0.50	2.625	4.27	1.00
Usability of Technology	5.8	3.75	1.50	3.875	4.45	1.00
Quality of Technology	4.8	3.625	1.50	5.25	4.09	0.50
Appropriate Tech Selection	2.6	3.5	1.00	2.375	4.09	2.00
Mobile Readiness	7.8	2.75	0.50	6.75	3.64	1.00
Real-Time Data Access	8	3	1.00	6.875	3.82	0.50
Limitations of Selected Technology	5.6	2.875	0.50	6.375	3.18	0.50
Technological Change & Development	9.2	2.625	0.00	10	3.00	0.00
Support from Tech Developers	7.6	3	2.00	8.75	3.00	1.50
Cloud Readiness	6.8	2.25	1.00	6.625	3.00	1.50
Abundance of Technological Options	4	2.5	0.50	6.5	2.64	1.00

Table 8: Delphi initial and final response data for Integration/Performance factors

ACT integration factor name	Initial response data (impact n=8, importance n=11)			Final response data (impact n=8, importance n=11)		
	Mean Impact Rank	Mean Importance Rate	IQR	Mean Impact Rank	Mean Importance Rate	IQR
Communication	3.8	4	0.50	2.5	4.27	1.00
Training	7.6	4.25	1.00	6.625	4.18	1.00
Project Team Champion	7.8	4.125	1.25	8	4.09	1.00
Implementation Flexibility	5.6	4.25	1.00	5.75	3.82	0.50
Planning	3.8	3.875	2.00	5.25	3.73	1.00
Comprehensiveness of New Tech Intro.	5.4	3.625	1.00	4.25	3.64	1.00
Demeanor of Implementation Professional	6.8	3.375	1.00	6.375	3.45	1.00
Result Driven Selection	7.8	3.375	1.25	9.375	3.36	1.00
Availability of Best Practices	5	3.375	2.25	4.25	3.36	1.50
Inclusion of Users in Solution Development	8	3.5	1.00	8	3.18	1.00
Incremental/ Phased Integration	6.2	3.375	1.25	7.25	3.18	1.50
Proximity of Support Team	10.2	2.625	1.25	10.375	2.73	1.50

Table 9: Initial response factor group ranking results by ACT integration factor category (n=5)

ACT Integration factor group	Kendall's coefficient of concordance (w)	Chi^2	p-value	Level of agreement
Organizational factors	0.39	21.5	0.029	Partial agreement
Personnel factors	0.51	25.2	0.005	Strong agreement
Technology factors	0.39	19.4	0.035	Partial agreement
Integration/performance factors	0.28	15.2	0.173	Partial Agreement

Partial agreement when using the combined IQR and agreement percentage criteria was achieved by 55% (25 of 46) of the factors. Strong agreement was achieved by 37% (17 of 46) of the factors during initial response. Consensus was achieved by 2 of 46 (4%) of the *Organizational* factor group: *Clear and direct benefit to user*, and *Organizational technology evaluation speed* with average Importance Ratings of 4.75 and 3.125 respectively. Finally, Disagreement was found on one factor each in the *Personnel* and *Integration/Performance* factor groups. The mean *Impact Rank* and mean *Importance Rating* established during the initial response period were displayed to the expert panelists at the start of the iterative response period along with the calculated IQR for the ratings and any comments written by panelists.

4.2.2 Final Response Data

The final response data was evaluated in two parts: holistically and based on groups determined by the job category of the panelists as described in the methodology. Cumulatively, the panelists did not achieve *Impact Ranking* consensus in any of the four ACT integration factor groups. Three of the factor groups, *Organizational, Personnel*, and *Integration/Performance*, achieved Partial agreement, with the *Technology* factor group achieving Strong agreement. These responses showed no meaningful change in the consensus achieved from the initial response period, however, the actual rankings of the factors did change between the two periods. Table 10 shows the Kendall's W and the Chi squared value for each of the factor groups. Additionally, the p-value was calculated for each group, based on the Chi squared approximation, to determine the level of confidence in the results. All factor groups proved significant with each yielding over 99% confidence, which validates the data for further analysis.

Table 10: Final response factor ranking results by ACT integration factor group category (n=8)

ACT Integration factor group	Kendall's coefficient of concordance (w)	Chi^2	p-value	Level of agreement
Organizational factors	0.41	35.6	0.00019	Partial agreement
Personnel factors	0.46	36.7	0.00006	Partial agreement
Technology factors	0.50	40.2	0.00002	Strong agreement
Integration/performance factors	0.40	34.8	0.00026	Partial Agreement

The independent *Importance Ratings* for the factors also showed improvement in the level of agreement achieved when compared to the initial response data. Strong agreement was achieved using the combined IQR and agreement percentage criteria for 56% (26 out of 46) factors. Partial agreement was achieved by 20% (9 of 46) factors and Consensus was achieved by 2% of factors (1 of 46). The number of factors in Disagreement increased from the initial response to 22% (10 of 46), with the majority of the factors in Disagreement belonging to the *Personnel* factor group.

The final response data for each factor is shown in Tables 5-8, where the data is separated by ACT integration factor group. Strong agreement pervades each of the factor groupings, with the *Personnel* factor group (see Table 6) showing the biggest discrepancy between Agreement and Disagreement, due to the requisite combination of IQR and agreement percentage. Overall, the level of agreement achieved for the importance ratings improved from the initial response, as expected, however consensus was not successfully achieved at high levels.

Technology integration strategies represent a complex area of study in which a multitude of individualized factors play a role. A variance in job roles; project types; previous experiences; personal beliefs; levels of expertise; and company strategies, all lead to different ideas among industry professionals as to how technology can be best integrated. Accordingly, the selected Policy Delphi style was used because the idea is to review all options, and the achievement of consensus is in a sense secondary. The highly experiential nature of an individual's interactions with construction technology are thus diametrically opposed to the goals of a rigid consensus driven Delphi. The information gathered during the iterative response period of this study provides insight into the complex topic of technological integration within the AECO industry, and merits further analysis and study moving forward.

4.2.3 Job Category Based Analysis

Following cumulative review and analysis, the final response data was separated based upon participants associated job category. Upon grouping, it was found that each job category achieved the following participation: VDC/technology upper management had two panelists complete the *Impact Rankings* and four complete the *Importance Ratings*; the BIM/VDC professionals had four panelists complete both; field/project personnel had two panelists complete the *Impact Rankings* and three complete the *Importance Ratings*. Table 11 shows the *Impact Ranking* data separated by ACT integration factor group and then by panelists job category.

Based on the grouping and sub grouping, Consensus was achieved twice, Strong agreement was achieved six times, and Partial agreement was found in four instances. The panelists agreed more on average with their direct peers than with those in other job categories in relation to the potential impact that technology integration factors might have. The job category with the highest level of agreement was the BIM/VDC professionals, who achieved Consensus for the impact ranking of *Personnel* factors and Strong agreement for the remaining integration factor groups. The level of agreement achieved for Impact Rankings within the BIM/VDC professional category is worth noting as it is the job category with the largest participation. This is indicative of deeper understanding of technological integration based on the fact that the BIM/VDC Professional job category represents those who are the most hands on with the technologies. The other two job categories are less hands on with the technologies themselves, and tend to be focused on divers outcomes, e.g. construction delivery, personnel management, executive level business planning, etc., which could be a factor which influenced the ability to achieve consensus.

The field/project personnel had two factor groups achieve Strong agreement with the other two Achieving partial agreement. The *Impact Ranking* showed improvements in agreement from the initial response data and a breakdown of the results by category shows even further improvement. The mean impact ratings achieved for each factor are shown in Tables 12-15 for each ACT integration factor group further separated by job category.

Table 11: Final response factor ranking results by ACT integration factor and job categories

Factor Group	Job category	Kendall's W	Chi^2	Level of agreement
Organizational factors	VDC/Tech Management	0.60	13.23	Strong agreement
	BIM/ VDC professional	0.57	25.12	Strong agreement
	Field/ Project personnel	0.45	9.92	Partial agreement
Personnel factors	VDC/Tech Management	0.69	13.72	Strong agreement
	BIM/ VDC professional	0.75	30.05	Consensus
	Field/ Project personnel	0.34	6.73	Partial agreement
Technology factors	VDC/Tech Management	0.82	16.45	Consensus
	BIM/ VDC professional	0.65	25.86	Strong agreement
	Field/ Project personnel	0.55	10.91	Strong agreement
Integration/ performance factors	VDC/Tech Management	0.46	10.08	Partial agreement
	BIM/ VDC professional	0.64	28.19	Strong agreement
	Field/ Project personnel	0.45	9.92	Partial agreement

A similar division of responses was conducted for the *Importance Ratings* based on the results of the iterative response period. The level of agreement for the *Importance Ratings* were calculated individually by factor, and as such were able to be evaluated based on the existence of 46 factors total. Divided by job category, the *Importance Ratings* showed higher levels of agreement in certain areas, with some factors still in Disagreement. Tables 12-15 show the mean *Importance Rate* for each factor separated by job category within their ACT integration groups.

The level of agreement achieved showed no discernable trends and varied largely depending on which job category was being evaluated. This indicates that an individual's job tasks or goals influence their perception of importance. The VDC/technology management panelists achieved consensus in 26% (12 of 46) of factor importance ratings across all four factor groups; Strong agreement in 59% (27 of 46); and Disagreement in 15% (7 of 46). Additionally, four of the seven factors in Disagreement belonged to the *Personnel* factor group indicating the differences in opinion were largely related to the role personnel have in technology integration itself.

Based on the data in Tables 12-15, the BIM/VDC professional job category of panelists achieved Consensus in 20% (9 of 46) of factor *Importance Ratings* across all four factor groups; Strong agreement in 17% (8 of 46); Partial agreement in 28% (13 of 46); Disagreement in 28% (13 of 46); and Split disagreement, where responses were polarized at the ends of the Likert scale in 7% (3 of 46). This category had individual factors with Disagreement in each of the factor groupings and the distribution for all agreement levels was mostly even among the categories. The *Integration/Performance* factor group was the most consistent for this job category with a majority of factors achieving Strong agreement and some Consensus. This finding supports the position that a BIM/VDC professionals hands on involvement with technology and performance contributes to a more clear vision of what works based on tangible experience.

Table 12: Delphi final response data for organizational factors by job category

Organizational factors	VDC/Tech upper management		BIM/ VDC professionals		Field/project personnel	
	Mean impact rank (n=2)	Mean importance rate (n=4)	Mean impact rank (n=4)	Mean importance rate (n=4)	Mean impact rank (n=2)	Mean importance rate (n=3)
Clear and Direct Benefit to User	1.5	4.75	1	5.00	3	4.67
Client Engagement	7	3.00	4.75	3.75	2.5	4.67
Contractual Requirement	6	2.50	5.25	3.00	6	4.00
Goal and Purpose Development	2.5	4.00	6	3.00	4.5	3.67
Cost Impact	7.5	3.25	5.75	4.25	6	3.67
Contract Delivery Method	6.5	3.00	9.5	2.50	7	3.67
Inclusion in Budget	6.5	2.75	5.5	3.00	6.5	2.67
Measurable Outcomes	10	3.50	5.75	4.00	7.5	4.33
ROI	4.5	4.00	5.5	4.25	8	3.33
Managing Expectations	8	3.75	8	4.00	10.5	3.00
Organizational Tech Evaluation Speed	11.5	2.75	10.25	2.75	6.5	2.67
R&D Time and Resources	6.5	3.25	10.75	2.25	10	2.67

Table 13: Delphi final response data for personnel factors by job category

Personnel factors	VDC/Tech upper management		BIM/ VDC professionals		Field/Project personnel	
	Mean impact rank (n=2)	Mean importance rate (n=4)	Mean impact rank (n=4)	Mean importance rate (n=4)	Mean impact rank (n=2)	Mean importance rate (n=3)
Appropriate Personnel	2.5	3.75	2.75	4.25	6	3.67
Field/Project Team Buy-In	3	4.5	2.5	4.50	4	4.00
Availability of Personnel	3.5	3.75	3	4.25	6	3.67
Leadership/Upper Management Buy-In	3	4.25	4.5	4.00	3.5	4.00
Forward Thinking Mentality (Future Benefit)	7.5	3.25	6.5	3.25	3.5	4.33
Learning Curve	8.5	3.25	4.5	3.75	6	3.00
Loss of Trust	4.5	4	5.25	4.00	9	2.33
Peoples' Resistance to Change	7	3.75	9	4.25	5.5	3.00
Previous Experiences or Use Case	10	3	8	3.50	9	3.33
Project Leadership Mentality	7.5	4.5	9.5	3.25	6	4.00
Tech Savviness of Project Team	9	3	10.5	3.25	7.5	4.33

Table 14: Delphi final response data for technology factors by job category

Technology Factors	VDC/Tech upper management		BIM/ VDC professionals		Field/Project personnel	
	Mean impact rank (n=2)	Mean importance rate (n=4)	Mean impact rank (n=4)	Mean importance rate (n=4)	Mean impact rank (n=2)	Mean importance rate (n=3)
Appropriateness of Tech to End-User	2	4.50	2.25	4.25	4	4.00
Appropriate Tech Selection	2	4.25	3	4.00	1.5	4.00
Abundance of Technological Options	9	2.50	5.25	2.75	6.5	2.67
Cloud Readiness	4	2.75	6.5	3.50	9.5	2.67
Limitations of Selected Technology	5	3.25	6.25	3.25	8	3.00
Quality of Technology	5	3.75	6	4.25	4	4.33
Mobile Readiness	6	3.75	6.5	3.50	8	3.67
Usability of Technology	4.5	3.75	3.5	4.75	4	5.00
Real-Time Data Access	8	3.25	5.75	4.50	8	3.67
Support from Tech Developers	9.5	3.00	10.25	3.00	5	3.00
Technological Change & Development	11	2.75	10.75	3.00	7.5	3.33

Table 15. Delphi final response data for integration/performance factors by job category

Integration/Performance factors	VDC/Tech upper management		BIM/VDC professionals		Field/Project personnel	
	Mean impact rank (n=2)	Mean importance rate (n=4)	Mean impact rank (n=4)	Mean importance rate (n=4)	Mean impact rank (n=2)	Mean importance rate (n=3)
Communication	4	4.50	1.5	4.25	3	4.00
Availability of Best Practices	6.5	3.50	2.75	3.50	5	3.00
Comprehensiveness of New Tech Intro	5.5	3.25	4	4.25	3.5	3.33
Implementation Flexibility	5.5	3.50	6	3.75	5.5	4.33
Demeanor of Implementation Professional	7	3.50	5.75	3.75	7	3.00
Planning	1.5	4.00	6.5	3.50	6.5	3.67
Incremental/ Phased Integration	10.5	3.25	6	3.25	6.5	3.00
Inclusion of Users in Solution Development	9.5	3.50	7.25	3.25	8	2.67
Project Team Champion	8	4.50	9.25	4.25	5.5	3.33
Training	5	4.25	7.5	4.50	6.5	3.67
Result Driven Selection	7	3.75	10.75	3.75	9	2.33
Proximity of Support Team	8	3.25	10.75	2.75	12	2.00

The field/project personnel job category of panelists achieved Consensus in 24% (11 of 46) of factor *Importance Ratings* across all four factor groups; Strong agreement in 54% (25 of 46); Disagreement in 20% (9 of 46); and Split disagreement in 2% (1 of 46). The factors achieving Split disagreement were reasonably well distributed among the factor groupings with no single group standing out as having more overall agreement than another. The large distribution of Strong agreement achieved indicates a general level of agreement similar to what was seen in the VDC/technology management category.

Overall, the BIM/VDC professional category achieved the lowest overall level of agreement, with a near even distribution among the four levels of agreement outlined for the *Importance Ratings*, however, they achieved the highest level of agreement for Impact Rankings. This dichotomy of results within the BIM/VDC professional category indicates that the group can clearly identify what causes problems with technology integration, yet disagrees on how to best address the issue. This is most likely due to the individual experiences that the panelists have worked through in their careers. The other two job categories achieved overall levels of agreement similar to one another, each with over 50% of the factors achieving Strong agreement. The VDC/technology management and field/project personnel categories also each had over 20% of factors achieve Consensus.

Based on the level of participation achieved and the individual nature of the topic being addressed, the lack of total consensus was expected and the levels of agreement make up a viable data set from which some conclusions can be drawn. There is no single solution to advanced technological integration, as there are too many variables. The variance in technologies and the processes which they impact, differences in construction market sectors, trade base variation based on region, and individual organizations goals are just some of the items which can impact specific rankings or ratings of factors. The importance ratings and impact rankings can be further analyzed and dissected to help isolate some of the mentioned variables, with the understanding that further study and additional Delphi participation would improve the data set as a whole.

5. CONCLUSION

The integration of emerging ACTs in the US AECO industry remains a slow process and, in a world where technology evolves rapidly, it is increasingly difficult for most US AECO companies to keep up. The AECO industry is one in which tight deadlines and the desire for ever faster construction times makes it difficult for companies to effectively plan for new technologies which can impact the workflow of daily operations. Additionally, there is no room for error when it comes to the integration of new technology, as delays are simply not an option and can be the difference between project success and failure. The diverse nature of the US AECO industry and ACTs themselves makes a single prescriptive methodology unrealistic.

The collection and evaluation of ACT integration factors through industry semi-structured interviews produced a set of variables to build the Delphi panel worksheet upon. Preliminary analysis, consolidation, and grouping of cited influential integration factors culminated in a total of 46 integration factors divided into four categorical groups. The *Organizational* and *Personnel* factor grouping demonstrated the highest level of repeated factor citations, 2.36 per factor on average, during the interview stage, while the *Technology* and *Implementation/Performance* categories had a high incidence of single citation factors. This finding furthered the initial impression that the technology itself, or past experiences with implementation, plays a primary role in how such future integrations will be perceived. This is something which was further researched during the Delphi phase of this study through the iterative review of such identified factors by a diverse group of industry professionals.

A novel Delphi methodology embedded in the newly developed DMS, enabled a continuously iterative evaluation process with the goal of fostering greater engagement and review of a topic which is of great interest to US AECO professionals. The continuously iterative style of the DMS allowed busy professionals to fit the study in when they were able to, however it also removed some of the typical control that researchers had over ensuring each panelist completed a certain number of reviews in a timely manner. The interaction with the system on the part of the participants was acceptable, and the ability for the researcher to evaluate interaction and review emerging trends in real-time proved helpful. Given a greater amount of time the level of interaction, and thus the quality of the collected data could be improved.

The Delphi results did not achieve full consensus in many of the impact ranking categories or individual importance ratings. However, the levels of strong agreement provided reasonable levels of understanding which were further bolstered through data analysis based on the defined job categories of the panelists. The Delphi study yielded several ACT integration factors which are either potentially important or impactful in achieving ACT integration success. Across all the integration factor groups, individual factors rose to the top of the *Importance Rating* or *Impact Ranking* data, along with themes related to the way professionals viewed technology integration.

It became clear from the results of the Delphi study that the way technology integration is viewed can vary greatly based on an individual's job or role within the industry. This was not unexpected but was confirmed during data analysis and provides an area of study for further research. Another limitation is the limited geographical area of the sample population that was secured for the semi-structured interviews and Delphi study. Although a large number of the participants came from companies serving national and international markets, they were all based in the eastern corridor of the United States. A third limitation is that most of the respondents were professionals in the commercial construction industry sector and as such representation from the industrial, residential and heavy highway industry sectors is lacking. Finally, the participants were primarily from large to medium sized international, national, regional and local companies. Future research should address these limitations by expanding the demographics of the participants.

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