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Global Application Patterns of 4D BIM in Construction: Sectoral Variation by Scale, Complexity, and Risk

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ABSTRACT

This paper showcases common global applications of 4D Building Information Modelling (4D BIM) across built environment industries and explains why these applications create higher returns on investment when considered against a project's size, complexity, and risk. The objective of this paper is to explain why certain categories of BIM implementation are executed more deeply across construction than others on a global scale. Qualitative methodology based on literature review was selected. Literature review consisted of desk research and subsequent comparative analysis of academic papers, trade journals, and policy papers (Davis, 1989) (Rogers, 2003) (Succar B. , 2009). Results show that 4D BIM is most commonly used on projects related to infrastructure and transportation, industrial and energy, health-care and other high-service buildings, and high-rise residential or prefabricated buildings (Lopez, Chong, Wang, & Graham, 2016) (Jin, Gambatese, Liu, & Dharmapalan, 2019) (Traore, Zhao, & Zhou, 2023). Following that criteria, projects were shown to have the most value when they had many interfaces, complex site logistics, important sequencing, increased safety risk, and expensive schedule float (Vassena, Perfetti, Comai, Mastrolembo Ventura, & Ciribini, 2023) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021) (Zhang, Zayed, Hijazi, & Alkass, 2016). There have been fewer cases of 4D BIM implementation on projects that are low-risk, small-sized, repetitive, and operationally simple where visualization would not produce enough value to justify implementation (Bryde, Broquetas, & Volm, 2013) (Gledson & Greenwood, 2017). In conclusion, 4D BIM implementation is selective across the world: when a construction project reaches a certain level of complexity, requires intense coordination, and has more temporal risk the more traditional planning methods fall short thus justifying the implementation of 4D BIM. (Koo & Fischer, 2000) (Hartmann, Gao, & Fischer, 2008).

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I. INTRODUCTION

Building Information Modelling (BIM) has developed over time from a model-based design technology into an information management ecosystem that facilitates planning, coordination, cost control and lifecycle decision-making (Eastman, Teicholz, Sacks, & Liston, 2012) (Holzer, 2023) (Sampaio, 2017). In that journey from 3D representation to nD process integration, 4D BIM holds a special place because it relates model geometry to schedule data and allows project teams to virtually simulate construction before it happens on site (Koo & Fischer, 2000) (Chau, Anson, & Zhang, 2004) (Heesom & Mahdjoubi, 2004). It follows that 4D BIM is less a visualization tool than a process management technology that can help identify sequencing conflicts, streamline logistics, support stakeholder communication and enable better monitoring and control (Hartmann, Gao, & Fischer, 2008) (Jin, Gambatese, Liu, & Dharmapalan, 2019) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021).

There is plenty of scope for those capabilities because construction projects are getting larger and more interface-heavy than ever before. Infrastructure projects have to move more earth, install more utilities, and assemble more structural components than in the past. Healthcare projects have denser technical systems that need to coordinate around space restrictions and infection control. Industrial projects require tight synchronization among specialist tradesto limit downtime and commissioning delays. Large-scale residential projects are also trending toward prefabrication, just-in-time delivery models, and tighter schedules (Lopez, Chong, Wang, & Graham, 2016) (Farnood Ahmadi & Arashpour, 2020) (Mayouf, et al., 2024). In all those cases, plain 2D drawings + bar charts + critical path schedules + spreadsheet-based coordination does not easily translate into clear visibility over work as it progresses in space and time (Doukari, Seck, & Greenwood, 2022) (Staub-French & Khanzode, 2007). The alternative tools are not useless or universally better, but they do have well-established limits of effectiveness when projects become more interdependent, time-critical and risk-loaded (Lawson & Ogden, 2006) (Radman, Jelodar, Lovreglio, Ghazizadeh, & Wilkinson, 2022).

We know from existing studies that 4D BIM can help with constructability review, schedule reliability, communication and proactive decision-making (Vassena, Perfetti, Comai, Mastrolembo Ventura, & Ciribini, 2023) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021) (Zhang, Zayed, Hijazi, & Alkass, 2016). We do not yet know as much about where those benefits accrue consistently, which sectors use 4D BIM most often, and how external conditions affect that behavior. Published research tends to treat projects individually: either as technical case studies, software demonstrations, or lessons learned from trying to implement 4D BIM on one project. Other scholars mention adoption barriers or stakeholder benefits in the abstract without clearly defining their project parameters (Bryde, Broquetas, & Volm, 2013) (Gong, Zeng, Ye, & König, 2019). As a result, it remains challenging to address the following question with confidence: where is 4D BIM actually utilized most frequently and effectively across global construction markets, and how are those application patterns shaped by sectoral conditions and workflows?

Answering that question is the central objective of this article. Specifically, this article asks: what are the predominant global application trends of 4D BIM across construction sectors, and how do those sectors differ in terms of project scale, complexity, and risk profile? Unlike some arguments that treat 4D BIM adoption as one uniform phenomenon across architecture, engineering and construction (AEC), this paper presents evidence that global usage trends are segmented according to sector. 4D BIM offers repeatable conditions for value creation in some sectors but not others, depending on need, readiness, and modelling ROI (Gledson & Greenwood, 2017) (Tran, Tran, & Nguyen, 2024). Isolating this question is worthwhile for both academic and professional audiences. Academic readers will appreciate a sector-sensitive synthesis that goes beyond anecdotal stories about how 4D BIM works everywhere or not at all. Professionals can use that same synthesis to make smarter adoption decisions in countries and markets that lack the resources, standards, or institutional capacity for wide-scale indiscriminate implementation (Nafe Assafi, Hossain, Chileshe, & Datta, 2023) (UNDP & ISBIH, 2020). If 4D BIM usage is concentrated among specific sectors worldwide, then decision-makers can prioritize those sectors for pilots, establish readiness criteria, and focus investments where the tool has proven its worth.

The position of this paper is that global application trends are defined by three criteria. First, project scale determines whether 4D BIM is used frequently because large projects have more activities, stakeholders, and downtime to lose. Second, project complexity drives 4D BIM use because intricate interfaces, technical systems, and restricted logistics demand integrated sequence planning. Third, project risk creates a need for 4D BIM because simulations are worth more when wrong decisions lead to higher costs, safety incidents, or operational failure (Bryde, Broquetas, & Volm, 2013) (Lopez, Chong, Wang, & Graham, 2016) (Mayouf, et al., 2024). Further, those three criteria tend to occur together in sectors where 4D BIM has been used repeatedly. Scale, complexity, and risk do not matter individually but jointly to distinguish projects where 4D BIM remains a ‘nice-to-have’ from those where it becomes a core strategic asset.

The remainder of this paper is structured as follows. Section 2 reviews literature on 4D BIM development, sector-specific applications, and evidence for main value drivers. That literature review places special emphasis on infrastructure, industrial, healthcare, and large-scale residential construction because they exhibit the highest global 4D BIM application frequencies. Methodology then describes the literature-based, cross-sector comparison used in this article. Results and discussion present global application trends and analyze them through the joint lenses of scale, complexity, and risk. Finally, conclusions reiterate the paper’s main argument and discuss implications for how people should understand thresholds of 4D BIM application.

II. METHODOLOGY

This paper uses qualitative literature-based research design augmented by desk research, comparative study, and interpretation. The focus is on prominent worldwide application trends for 4D BIM across building sectors. Therefore, adoption levels are not statistically quantified, nor is a causal model formally tested against field data. Reported patterns, enabling conditions, and associations recur throughout the dataset of literature reviewed for this study (UNDP & ISBIH, 2020) (Tran, Tran, & Nguyen, 2024).

Data consists of journal articles, conference papers, standards-related literature, strategic BIM reports, and selected industry publications that were part of the reviewed literature. This evidence was appropriate because this paper responds to an interpretive inquiry about where 4D BIM tends to be applied and under what project conditions its value is most frequently cited. Sources that covered either successful use cases or adoption hurdles were reviewed because worldwide trends are more apparent when successful examples are juxtaposed with information on limiting conditions and barriers (El-Habashy, Alqahtani, Mekawy, Sherif, & Badawy, 2023).

The analysis was comparative, not only descriptive. Rather than reporting on literature for each sector independently and without consistent framework, this paper discusses sectors in relation to the same variables:

size and technical complexity, organizational complexity and logistical intensity, inherent risks or consequences of failure, primary use cases that authors have reported, and project management benefits that respondents and researchers expect from 4D BIM. Comparing sectors according to common variables was appropriate because the research question asked about differences among them. Highlighting similarities and differences positions the paper to articulate thresholds that recur across sectors. (Bryde, Broquetas, & Volm, 2013) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021)

Sectorality was categorized based on groupings used in this paper: Infrastructure and transport; industrial facilities and energy projects; healthcare and other highly serviced buildings; and mass housing or repetitive projects. Industrial groupings were not used rigidly. For example, shelter includes commercial, institutional, and residential projects when discussing sectors with large-scale or modular/logistics intensive features. The point of sectoral groupings is to enable comparison across contexts that are unique in workflow logic, stakeholder make-up, and requirements for communication and coordination. Routine projects of small scale were used as a referent category to better understand where literature suggests fewer incentives or requirements for intensive 4D BIM application. (Lopez, Chong, Wang, & Graham, 2016) (Jin, Gambatese, Liu, & Dharmapalan, 2019)

Technology Acceptance Model theory and Diffusion of Innovations theory help frame this study. For purposes of the current paper, however, they are used as a secondary lens through which findings are interpreted, not as the focal theory. The main contribution of this paper is description of application trends, not explanation. Nevertheless, TAM and DOI are useful because they can help explain why certain sectors are quicker to adopt 4D BIM. Perceived usefulness increases when time-related challenges are expensive to produce or detect. Perceived ease of use decreases when 4D BIM workflows, required data, and coordination demands are complex. Similarly, diffusion occurs when other firms can see a relative advantage and when pilot results are measurable. (Davis, 1989) (Rogers, 2003) (Gong, Zeng, Ye, & König, 2019)

Study was performed by coding for claims and examples that recurred across multiple sources in the dataset, then organizing those excerpts into themes. Attention was given to examples of projects where authors describe positive effects from 4D BIM uses related to simulation of construction sequence, logistics or resource planning, stakeholder engagement, progress monitoring, and constructability analysis. Reported applications were interpreted with regard to the three primary variables of interest in this paper: project scale, project complexity, and project risk. Applications were not scored for each sector based on a point system or quantitative metric. Qualitative descriptions were analyzed for patterns and used to form a narratively sound conclusion about which conditions correlate with heightened sectoral demand for 4D BIM. (Hartmann, Gao, & Fischer, 2008) (Zhang, Zayed, Hijazi, & Alkass, 2016)

Limitations of this paper should be noted. First, it relies on secondary data rather than generating new data through primary research. As such, its findings will reflect both the strengths and biases of published research. Highly studied sectors may seem larger because more publications exist about them. Second, the paper focuses on repeated global trends rather than providing detailed coverage of every country or project type. Third, comparisons made between sectors are interpretive, based on literature rather than hard measures of project outcomes. The method still suits the research question, however, because application trends can only be answered through conceptual synstudy of evidence from multiple sectors. The reviewed literature is also broad enough to enable that analysis.

III. RESULTS AND DISCUSSION

The findings align globally in demonstrating prominent use of 4D BIM within sectors where time-related interfaces are more complex to coordinate and expensive to remediate during construction. This lends credence to previous studies that found uptake of 4D BIM is far from universal (Lopez, Chong, Wang, & Graham, 2016) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021). The four clusters identified throughout the literature recur with some regularity: infrastructure and transportation; industrial facilities and power generation; hospitals/medical centers and high-service buildings; and high-rise residential and prefabricated buildings (Jin, Gambatese, Liu, & Dharmapalan, 2019) (Traore, Zhao, & Zhou, 2023). Despite differing in composition, all four sector groupings share a common theme: increasing numbers of interfaces, dependencies, and ramifications from sequencing mistakes equates to greater benefits from employing 4D BIM from a management perspective.

Similarly consistent patterns can be noted regarding the purposes 4D BIM serves across sectors. Rarely is it used for the purpose of visualization alone. More commonly, projects implement time as the 4th dimension of building information modelling to facilitate phase planning; coordinate 'temporary works'; manage workspace and restrictions; orchestrate logistical sequences; communicate with stakeholders; or enable decision-making based on project progress. Recognition of this fact is valuable as it separates productive uses of the technology from efforts to 'digitise for digitise's sake'. Software is leveraged most effectively where it becomes embedded into planning and control processes, rather than being siloed as a visualization exercise for meetings (Hartmann, Gao, & Fischer, 2008) (Deng, Gan, Das, & Cheng, 2019).

It is perhaps unsurprising that infrastructure and transportation initiatives feature most frequently throughout the literature as high-value sectors for 4D BIM. Roads, railways, bridges, tunnels, airports, metros, and utilities frequently represent large-scale projects that are linear in nature, publicly exposed, and subject to high-level constraints around traffic management, safety, utility relocation, environment plans, sequencing of access, and so forth (Lopez, Chong, Wang, & Graham, 2016) (Zhang, Zayed, Hijazi, & Alkass, 2016).

Not only can a poor sequence negatively impact the contractor's ability to work efficiently, but the public's ability to move freely can also be affected along with stakeholder relationships and regulatory approvals.

Predominant uses for 4D BIM within this sector cluster primarily revolve around phasing and managing interfaces. Project teams are visualizing lane closures; analyzing diversion lengths; mapping staging areas and hard-to-access equipment; or detailing transitions along the work-front through 4D simulations. For linear infrastructure in particular, seeing how crews, materials, and temporary facilities are distributed over both space and time allows for a better interpretation of how these elements will actually be managed. Although a schedule may provide start and finish dates alongside activity durations, it does not explicitly communicate how overlapping activities will interact along the physical corridor. Consequently, scholars have directly linked the use of 4D BIM within infrastructure to improved communication between designers, planners, contractors, authorities, and affected members of the public (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021) (Vassena, Perfetti, Comai, Mastrolembo Ventura, & Ciribini, 2023).

Needless to say, another reason infrastructure projects may register strong usage statistics is due to the high risk associated with their delivery. Traffic environments are live, often heavily used by the public, and can attract severe penalties for delays or substandard work. Within these contexts, the relative advantages of 4D BIM can become quite apparent. While certain aspects of trialability may be more difficult in large-scale infrastructure projects, this need not be the case if pilot packages or segments of the corridor are selected. Benefits such as fewer misunderstandings, improved staging logic, or visibly communicated stakeholder impacts can be easily observed by reviewers. All of these factors help explain why infrastructure and transportation continues to emerge as one of the leading sectors for 4D BIM use globally (Rogers, 2003) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021).

Clusters of industrial and energy facilities represent the second major application group identified throughout literature, and in some ways represents a stronger grouping with regard to 4D BIM's sensitivity to sequencing. Power stations, refineries, manufacturing plants, processing facilities, and EPC/on-site construction projects routinely involve complex equipment layouts; extensive multi-disciplinary coordination; planned shutdown periods; safety-critical interfaces; and stringent commissioning requirements (Gong, Zeng, Ye, & König, 2019) (El-Habashy, Alqahtani, Mekawy, Sherif, & Badawy, 2023). Mishaps during construction can cause extreme cost overruns and logistical headaches when working spaces are tight, replacement parts are specialized, or access conditions are difficult to achieve.

Research shows 4D BIM is commonly used to address constructability issues and plan installation of large components within industrial projects. Model viewers simulate cranes lifting and placing equipment; plan the transportation routing of large or heavy components; manage congestion around plant rooms or equipment clusters; coordinate specialist contractor packages; and determine how to sequence around limited access points or occupied equipment. By contrast with simpler projects, industrial facilities demand careful consideration around how physical construction can occur within the built environment. Highly technical specifications must be married with realistic planning that considers how and when people and materials can access the worksite. Drawings and spreadsheets alone are comparatively ineffective at communicating this information (Farnood Ahmadi & Arashpour, 2020).

Risk once again becomes a central theme for understanding technology adoption. Industrial projects are commonly high-value; work under hazardous conditions; have intensive testing requirements; and suffer greatly from downtime or failed commissioning. Therefore, the perceived benefits of 4D BIM can easily outweigh its costs to implement. Though there may be significant up-front demands associated with modelling at this level of complexity, the consequences of failure create strong justification for projects to get it right the first time. Recognizing why industrial projects represent a key area of focus helps explain scholarly repetition surrounding energy and industrial facilities as premier use-cases for 4D BIM worldwide (Bryde, Broquetas, & Volm, 2013) (Mayouf, et al., 2024).

Healthcare projects are a building-sector context where 4D BIM becomes valuable due to an internal complexity approaching external coordination challenges in infrastructure and industrial projects. Hospitals and clinics feature complex MEP systems, heavy equipment, specialized room standards, precise commissioning sequences, and user-related constraints. When these are bundled with renovate-as-you-go conditions during refurbishment and extension projects, disruption needs to be carefully managed alongside construction works (Lopez, Chong, Wang, & Graham, 2016) (Vassena, Perfetti, Comai, Mastrolembo Ventura, & Ciribini, 2023).

Authors focus on issues of communication and coordination in healthcare use cases. Project teams (construction and facility management), designers, and end users often require assurances on how phased construction will impact access routes, utility availability, patient zones, and technical shutdowns. 4D BIM can help develop a shared understanding by translating program logic into a visual format that can be assessed by laypersons. Mapping out potential routes for temporary accommodation, service outages, or handover sequences becomes easier. Although second order to some project teams, the communicative benefits of the technology are critical in healthcare settings to minimize confusion and rejection (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021).

The healthcare sector also illustrates how complexity relates to observability. If sequencing errors cause visibly disruptive outcomes, such as delayed commissioning, halted operations, inaccessible areas, or rework, you are more likely to see the benefit. Applied to 4D BIM adoption, this suggests that professionals can overcome modelling barriers when usefulness is high enough. In other words, healthcare projects help confirm the paper's thesis that complexity and risk increase perceived usefulness above the threshold required for regular use (Davis, 1989) (Rogers, 2003).

Residential construction shows a contrasted pattern. Simple projects such as low-rise residential buildings or other small-scale housing work are not typically where you find the bulk of 4D BIM papers. Construction sequencing on these projects is often less novel, site logistics are easier to orchestrate, and benefits may not outweigh the costs of developing and managing a detailed 4D model. It does not mean 4D BIM has no purpose in residential applications; it means that necessity is often lower when projects have fewer complex components, less tightly coupled dependencies, and higher tolerance for comparatively sloppy scheduling practices (Gledson & Greenwood, 2017).

Outcomes differ when reviewing large-scale, high-density, mixed-use, or residential developments that rely on prefabricated components and modules. Literature related to these contexts does describe regular 4D BIM usage for tower building sequencing, vertical logistics, façade erection, crane scheduling, layout of floor zones, and handing over of off-site elements. Projects with fast tracks or complicated site conditions benefit from visualizing material deliveries and spatial conflicts around limited workspace. Regarding off-site and modular construction, 4D BIM can be used for ensuring alignment between factory production schedules and transport, lifting, storage, and build logistics (Lawson & Ogden, 2006) (Mayouf, et al., 2024).

In short, residential building supports the paper's central argument if sectors are disaggregated into project types. Simply assigning sectors does not reliably predict 4D BIM value. Instead, a sector can host both strong and weak applications of the technology depending on the projects involved. The primary difference between use cases is whether a residential building project maintains low complexity or crosses a threshold into being complicated enough to produce high coordination needs.

Comparing all four sectors more directly, it becomes clear that scale is an essential but incomplete factor. Bigger projects tend to feature more activities, longer timelines, and more complexity; hence they adopt 4D BIM more frequently. But this is not the whole story, as scale can be present without strong 4D BIM usage. A high-rise housing development might still involve simple repetitive tasks and little spatial limitation. Complexity describes the patterns of interfaces, technical systems, trade overlap, and phasing dependencies more directly related to a need for visualization capabilities (Lopez, Chong, Wang, & Graham, 2016).

Risk exposure rounds out the explanation. Reviewing the articles, very few exist about 4D BIM where delays are simply undesirable. The majority describe projects where delay or failure in sequencing would lead to cost overruns, safety incidents, operational breakdowns, reputational harm, or public inconvenience. Infrastructure constructions, industrial outages, hospital turnarounds, and high-density residential developments all fit these criteria. It stands to reason that features making you "lose" if scheduling fails also make time invested in 4D BIM more economically justifiable and managerial noticeable (Zhang, Zayed, Hijazi, & Alkass, 2016) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021).

Logistics concerns are interesting because they act as something of a crossover factor between complexity and risk. Site congestion, limited access, restricted storage, temporary traffic management, crane activities, and just-in-time material deliveries are frequent reasons authors cite for using 4D BIM. Logistics becomes a concern when complex interdependencies require more finesse during execution. Static tools reach a limit where teams must manage how people and materials move around, when they have access, where things can be staged, and how trade should collaborate. When that limit is reached, adding a 4D tool can seem less expensive or stressful than physical ideation alone (Mayouf, et al., 2024).

Yet another strong correlation exists with stakeholder diversity. Projects that engage many parties – across the design team, main and subcontractors, operators and regulators, future users, investors, and public stakeholders – also have higher chances of benefiting from visual planning, because 4D BIM helps close interpretation gaps. While this communications benefit may seem self-evident, it is worth emphasizing that the most direct value of 4D BIM may often be less about mathematically optimizing the schedule than about translating complicated execution logic into something every stakeholder can understand across disciplinary silos. Simply building a better shared understanding can help avoid delay and rework as well (Hartmann, Gao, & Fischer, 2008) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021).

Equally present in the literature review are cases where high-value sectors also need certain enabling conditions to be met. The fact that certain applications are very strong does not imply that they will automatically succeed. If schedule data quality is poor, model development is weak, or teams are incapable of maintaining and using simulations as working management tools, any investment in 4D BIM may simply produce impressive-looking outputs that fail to influence delivery metrics. Hence, many studies link success to factors like overall model quality, interoperable production workflows, organizational maturity, and specialized coordination skills (Azhar, 2011) (Lee, Oh, Kim, & Choi, 2015) (Gledson & Greenwood, 2017). Global application patterns are as much about implementation realities as demand.

Taken together, these insights provide a complete answer to the first research question. Areas of dominant global 4D BIM application are those where several drivers of project scale, coordination complexity, and risk converge to create clear demand for the temporal integration of visual planning. Infrastructure and transportation leads due to phasing complexity, stakeholder exposure, and sheer interface quantity. Industrial and energy guide closely because they are technically dense while also facing extended shutdown periods and safety-critical coordination. Healthcare was an instructive exception that proves the rule—building sector projects can face just as tricky problems if services and uptime are sensitive. Large-scale residential and modular construction also appear, illustrating how the value of 4D BIM climbs once repetition gives way to logistical challenges like vertical delivery, prefabrication, compressed schedules, or urban constraints (Lopez, Chong, Wang, & Graham, 2016) (Jin, Gambatese, Liu, & Dharmapalan, 2019) (Mayouf, et al., 2024).

Ultimately, the point is that 4D BIM is not a silver bullet to be universally mandated across all construction projects. Looking across its strongest areas of global application, the academic literature suggests a logic of selective deployment in which the tool offers greatest value after project characteristics pass certain thresholds of geometric, logistical, or human complexity. For decision-makers focus on long-term planning under resource constraints, this conclusion should carry significant weight. When funds and talent are limited, attempting to deploy 4D BIM everywhere may become a self-defeating goal. Sector-based guidelines can help organizations and governments prioritize early wins where international experience shows the strongest benefits (Nafe Assafi, Hossain, Chileshe, & Datta, 2023).

IV. CONCLUSION

“The intent of this paper was to provide a answer to a narrowly defined question,” which was posed in this article. That question was: where, globally, is 4D BIM most commonly applied across the construction industry, and why? Does project size, complexity, or risk influence application patterns? Reviewing existing literature allows us to conclude that use of 4D BIM around the world is weighted toward construction sectors where: (1) process coordination is complex; (2) temporal uncertainty is expensive; and (3) traditional planning methodologies fail to adequately visualize construction activity as it will unfold (Lopez, Chong, Wang, & Graham, 2016) (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 4D BIM for Construction Logistics Management, 2021).

We find four sectors/categories/themes of construction that regularly overlap in literature regarding high utilization of 4D BIM. Infrastructure and transportation because they usually require phase delivery, public interaction management, and sequencing across long-span, operationally constrained sites. Industrial and energy because of their dense technical systems, restricted access, scheduled downtime, and the safety and cost risks involved with improper sequencing. Healthcare and high-service buildings due to the internal complexity, coordination of services, and operational uptime requirements. Large and/or modular residential where the size of the project, vertical logistics, offsite fabrication, or urban constraints render traditional planning methods inadequate (Jin, Gambatese, Liu, & Dharmapalan, 2019) (Mayouf, et al., 2024).

Through comparative analysis of literature, we interpret that project complexity is the primary factor; further compounded by logistical density and high consequence of delay. Project size is influential because it typically correlates with more interfaces to coordinate. Project risk is influential because it raises the stakes from sequencing being “best practice” to sequencing needing to be “done right.” Between them, these factors help explain application trends of 4D BIM across different sectors of construction (Bryde, Broquetas, & Volm, 2013) (Zhang, Zayed, Hijazi, & Alkass, 2016).

The scholarly implication of this work is that researchers should view 4D BIM as a technology whose adoption is predicated on conditional factors; not something that becomes table-stakes at a certain level of digital maturity. The industry implication of this work is that those who can influence 4D BIM adoption should focus on sectors where scale, complexity, logistics, and risk interact to create clear value from its usage. This finding can help guide 4D BIM adoption where it matters most, specifically in developing or resource-constrained economies where adoption can be more targeted than in established markets (Rogers, 2003) (UNDP & ISBIH, 2020).

As it was restricted to secondary resources and synthesis of existing knowledge, this paper has some limitations. For instance, future work would do well to investigate the application pattern we identified here through sector-specific case studies, project performance analysis, and interviews with planners/project teams. Nevertheless, we can conclusively say that 4D BIM is applied most frequently to projects from the above sectors: where planning is complex, communication risk is high, and mistakes are very costly.

REFERENCES

[1]. Azhar, S. (2011). Building Information Modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering, 11*(3), 241–252. doi:10.1061/(ASCE)LM.1943-5630.0000127

[2]. Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of Building Information Modelling (BIM). *International Journal of Project Management, 31*(7), 971–980. doi:https://doi.org/10.1016/j.ijproman.2012.12.001

[3]. Chau, K. W., Anson, M., & Zhang, J. P. (2004). Four-Dimensional Visualization of Construction Scheduling and Site Utilization. *Journal of Construction Engineering and Management, 130*(4), 598–606. doi:https://doi.org/10.1061/(ASCE)0733-9364(2004)130:4(598)

[4]. Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340.

[5]. Deng, Y., Gan, V. J., Das, M., & Cheng, J. C. (2019). Integrating 4D BIM and GIS for construction supply chain management. *Journal of Construction Engineering and Management, 145*(2). doi:10.1061/(ASCE)CO.1943-7862.0001633

[6]. Doukari, O., Seck, B., & Greenwood, D. (2022). The efficient generation of 4D BIM construction schedules: A case study of the Nanterre 2 CESI project in France. *Frontiers in Built Environment, 8*, Article No.: 998309. doi:https://doi.org/10.3389/fbuil.2022.998309

[7]. Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2012). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors* (2nd ed.). Wiley. doi:https://doi.org/10.5130/AJCEB.v12i3.2749

[8]. El-Habashy, S., Alqahtani, F. K., Mekawy, M., Sherif, M., & Badawy, M. (2023). Identification of 4D-BIM barriers in offshore construction projects using fuzzy structural equation modeling. *Buildings, 13*(6), Article No.: 1512. doi:10.3390/buildings13061512.

[9]. Farnood Ahmadi, P., & Arashpour, M. (2020). An analysis of 4D-BIM Construction Planning: Advantages, Risks and Challenges. *37th International Symposium on Automation and Robotics in Construction*, (p. 0025). doi:https://doi.org/10.22260/ISARC2020/0025

[10]. Gledson, B. J., & Greenwood, D. (2017). The adoption of 4D BIM in the UK construction industry: An innovation diffusion approach. *Engineering, Construction and Architectural Management, 24*(6), 950–967. doi:https://doi.org/10.1108/ECAM-03-2016-0066

[11]. Gong, P., Zeng, N., Ye, K., & König, M. (2019). An Empirical Study on the Acceptance of 4D BIM in EPC Projects in China. *Sustainability*, 11(5), 1316. doi:https://doi.org/10.3390/su11051316

[12]. Hartmann, T., Gao, J., & Fischer, M. (2008). Areas of Application for 3D and 4D Models on Construction Projects. *Journal of Construction Engineering and Management, 134*(10), 776–785. doi:https://doi.org/10.1061/(ASCE)0733-9364(2008)134:10(776)

[13]. Heesom, D., & Mahdjoubi, L. (2004). Trends of 4D CAD applications for construction planning. *Construction Management and Economics, 22*(2), 171–182. doi:https://doi.org/10.1080/0144619032000159866

[14]. Holzer, D. (2023). *Design Technology in Contemporary Architectural Practice* (1st ed.). Routledge. doi:https://doi.org/10.4324/9780429460722

[15]. Jin, Z., Gambatese, J., Liu, D., & Dharmapalan, V. (2019). Using 4D BIM to assess construction risks during the design phase. *Engineering, Construction and Architectural Management, 26*(11), 2637–2654. doi:https://doi.org/10.1108/ECAM-09-2018-0379

[16]. Koo, B., & Fischer, M. (2000). Feasibility Study of 4D CAD in Commercial Construction. *Journal of Construction Engineering and Management, 126*(4), 251–260. doi:https://doi.org/10.1061/(ASCE)0733-9364(2000)126:4(251)

[17]. Lawson, R. M., & Ogden, R. G. (2006). Hybrid systems in light steel and modular construction. *Adaptables 2006: International Conference on Adaptable Building Structures*, (pp. 3-252–3-256). Eindhoven. Retrieved from https://www.irbnet.de/daten/iconda/CIB10841.pdf

[18]. Lee, H. W., Oh, H., Kim, Y., & Choi, K. (2015). Quantitative Analysis of Warnings in Building Information Modeling (BIM). *Automation in Construction, 54*, 23–33. doi:10.1016/j.autcon.2015.08.010

[19]. Lopez, R., Chong, H.-Y., Wang, X., & Graham, J. (2016). Technical Review: Analysis and Appraisal of Four-Dimensional Building Information Modeling Usability in Construction and Engineering Projects. *Journal of Construction Engineering and Management, 142*(5), Article No.: 06015005. doi:https://doi.org/10.1061/(ASCE)CO.1943-7862.0001094

[20]. Mayouf, M., Jones, J., Elghaish, F., Emam, H., Ekanayake, E. M., & Ashayeri, I. (2024). Revolutionising the 4D BIM Process to Support Scheduling Requirements in Modular Construction. *Sustainability, 16*(2), 476. doi:https://doi.org/10.3390/su16020476

[21]. Nafe Assafi, M., Hossain, M. M., Chileshe, N., & Datta, S. D. (2023). Development and validation of a framework for preventing and mitigating construction delay using 4D BIM platform in Bangladeshi construction sector. *Construction Innovation, 23*(5), 1255–1278. doi:10.1108/CI-08-2021-0160

[22]. Radman, K., Jelodar, M. B., Lovreglio, R., Ghazizadeh, E., & Wilkinson, S. (2022). Digital technologies and data-driven delay management process for construction projects. *Frontiers in Built Environment, 8*, Article No.: 1029586. doi:https://doi.org/10.3389/fbuil.2022.1029586

[23]. Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York: Free Press (Simon & Schuster). Retrieved from https://books.google.ba/books/about/Diffusion_of_Innovations_5th_Edition.html?id=9U1K5LjUOwEC&redir_esc=y

[24]. Sampaio, A. Z. (2017). BIM as a Computer-Aided Design Methodology in Civil Engineering. *Journal of Software Engineering and Applications, 10*(2), 194–210. doi:https://doi.org/10.4236/jsea.2017.102012

[25]. Staub-French, S., & Khanzode, A. (2007). 3D and 4D modeling for design and construction coordination: Issues and lessons learned. *Journal of Information Technology in Construction (ITcon), 12*, 381–407. doi:https://www.itcon.org/2007/26

[26]. Tran, T. V., Tran, H. V., & Nguyen, T. A. (2024). A Review of Challenges and Opportunities in BIM Adoption for Construction Project Management. *Engineering Journal, 28*(8), 79–98. doi:https://doi.org/10.4186/ej.2024.28.8.79

[27]. Traore, M., Zhao, G., & Zhou, X. (2023). Simulation of the Construction of a Swivel Bridge Using BIM 4D. *Open Journal of Civil Engineering, 13*(1), 139–154. doi:https://doi.org/10.4236/ojce.2023.131010

[28]. UNDP, & ISBIH. (2020). *Concept document for BIM implementation in Bosnia and Herzegovina.* Institute for Standardization of Bosnia and Herzegovina. Retrieved from isbih.gov.ba PDF

[29]. Vassena, G. P., Perfetti, L., Comai, S., Mastrolembo Ventura, S., & Ciribini, A. L. (2023). Construction Progress Monitoring through the Integration of 4D BIM and SLAM-Based Mapping Devices. *Buildings*(10), 2488. doi:https://doi.org/10.3390/buildings13102488

[30]. Whitlock, K., Abanda, F. H., Manjia, M. B., Pettang, C., & Nkeng, G. E. (2021). 4D BIM for Construction Logistics Management. *CivilEng, 2*(2), 325–348. doi:https://doi.org/10.3390/civileng2020018

[31]. Whitlock, K., Abanda, F. H., Manjia, M. B., Pettang, C., & Nkeng, G. E. (2021). 4D BIM for Construction Logistics Management. *CivilEng, 2*(2), 325–348. doi:10.3390/civileng2020018

[32]. Zhang, C., Zayed, T., Hijazi, W., & Alkass, S. (2016). Quantitative Assessment of Building Constructability Using BIM and 4D Simulation. *Open Journal of Civil Engineering, 6*(3), 442–461. doi:https://doi.org/10.4236/ojce.2016.63037