Incorporating Emerging Technologies in the Forensic Analysis of Construction Project Delays

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Abstract. Considering the significant role of the construction industry in the global economy, its continuous adoption of new technological advances is both desirable and inevitable. These advances include Building Information Modelling (BIM) and Artificial Intelligence (AI)/Machine Learning (ML). However, not all sections of the industry currently embrace these developments. Forensic Delay Analysis (FDA) is an activity of specialists in extracting and presenting evidence contractual claims disputes that relate to project delays. Such delays are frequent and expensive, but the FDA process has benefitted little from these new technologies. The paper reports the initial work of a collaborative PhD project funded under the Intensive Industrial Innovation Programme of the European Regional Development Fund. The project explores the integration of BIM and AI/ML technologies within the FDA process. The potential of emerging technologies in different parts of the FDA process is first considered, followed by a systematic literature review (SLR) of published work that might support, refute, or exemplify such contributions. The findings show that BIM and AI/ML offer promising solutions to the current challenges of FDA and opportunities for enhancing the effectiveness of dispute resolution, but further work is needed to test the proposed improvements on real-world project workflows and to collect expert feedback to assess their effectiveness.

1. Introduction

The construction industry has a significant role in the global economy with an annual output of US$10.7 trillion in 2020 [1]. Its adoption of technology is noticeably slower than other sectors, though the potential is massive [2, 3]. The focus of this paper is the adoption of emerging technologies for the more efficient and effective settlement of disputes emerging from project delays. It is indicated that approximately 72% of construction projects face delays to their original contracted duration of an average of 38% [4]. These delays, in turn may result in disputes. The global average time spent on a construction dispute is 13.4 months and their global average value is US$54.26 million [5]. Accordingly, the analysis of delays is crucial and has created a specialist niche for consultants in what is now commonly termed forensic delay analysis (FDA). This paper is part of an investigation into the impact of new technologies on FDA. After a background introduction to FDA and its current challenges, we examine opportunities that emerging technologies might offer. There follows a presentation of the outcomes of a systematic literature review (SLR) on this potential. The findings of the review are then discussed and the conclusions and the future ambitions of the study are presented.

2. Background, challenges, and opportunities

2.1. Delays, claims and disputes

As Burr and Pickavance [6] observed, the term *delay* is open to several interpretations that can themselves be the source of dispute. Causes of project delay have been investigated extensively: a recent summary of this topic is provided [7]. To compensate for the adverse effects of delay, the parties to a construction contract may, under the contractual provisions make a *claim* (defined in the FIDIC "Red Book" [8] as *"a request or assertion … for an entitlement or relief … in connection with… the Contract or the execution of the Works*"). Claims may develop into *disputes* that entail (in order of increasing hostility and cost) independent review, mediation, mini-trial, adjudication, arbitration, or litigation [9]. Every method requires the extensive sourcing, analysis and presentation of evidence. In delay disputes this process is described as forensic delay analysis (FDA) and has become the province of expert consultants [10]. It is described that the FDA process as comprising three stages: (i) information retrieval, (ii) delay analysis, and (iii) communication of the findings. At each stage there are challenges and shortcomings [11].

2.2. Assumed challenges and shortcomings in the FDA process

2.2.1. Information retrieval. Vidogah and Ndekugri [12] found that the identification, sourcing, and retrieval of relevant information was the most time-consuming and costly of all aspects of claims preparation. They concur with many authors that *"the construction industry is notorious for not documenting procedures and transactions"*. Thus, the first serious challenge to the FDA process concerns the quality, availability, and transparency of relevant information. It has been estimated that this stage currently represents 70% of the entire FDA effort [13].

2.2.2. Analysis of the delay. Axelson [14] stated that a method of FDA to be considered as *"an algorithm for generating a model of the causal nexuses between, on the one hand, processes and events that give rise to delay (i.e. 'causes') and on the other hand, the resultant changes to the forecast or predicted completion time of the project (i.e. the 'effects')"*. Parry [15] revealed a confusing multiplicity of delay analysis methods. Their variability is to some extent mitigated by the work of the Society of Construction Law [16] and the American Association of Cost Engineering [17], but the proper application of the preferred methods is highly dependent on adequate supporting information; which is in itself problematic, as observed above.

2.2.3. Communication of the findings as evidence. As stated earlier, whatever the forum in which claims or dispute resolution takes place, evidence will need to be presented. A major challenge is in presenting complex information, including technical drawings and schedules, to those unfamiliar with it [18]. This is particularly the case when a dispute has escalated as far as arbitration or litigation.

2.3. Potential opportunities presented by emerging technologies

It is argued that technological advances are recognised as the processes to make construction more efficient, competitive and valuable [19]. Some of the recent ones that drive Construction 4.0 offer opportunities to address the above challenges of the FDA process. The two areas of interest here are BIM (and, more broadly, digitisation of information) and the use of artificial intelligence. There follows propositions of how they might do so.

2.3.1. Building Information Modelling. The use of BIM offers significant advantages to the design, delivery and in-use management of the construction product [20] and its process, by boosting productivity, managing complexity, and enhancing safety and quality [21]. The use of so-called "4D BIM" (combining a time dimension with the 3D-model) may not only improve construction scheduling

but enable the visualisation of activities and communicate them more easily [22]. It should thus be possible to exploit these same advantages retrospectively in the FDA process.

2.3.2. Artificial intelligence and machine learning. Artificial intelligence (AI) entails the creation of smart machines and computer systems that can learn and replicate the activities of the human brain. AI, and in particular machine learning (ML) already plays a crucial role in several industries, and can help overcome many of the challenges faced by construction [23]. In terms of FDA, it is likely to offer enhancement at the interface between the *information management* and *analysis* stages of the overall FDA process.

3. Research methodology and SLR results

A systematic literature review (SLR) was carried out to examine the opportunities afforded to the FDA process by BIM and AI/ML. First, four databases (Scopus, Web of Science, Science Direct and Google Scholar) were interrogated. Alternative keywords, acronyms, specialist terms, spelling variations and truncations were included to enhance the search. The search was restricted to conference proceedings, dissertations, journal articles, interviews, government documents, and independent organisations' reports. The titles, abstracts and keywords of these publications were subjected to three basic query strings (BIM+FDA, BIM+AI/ML, FDA+AI/ML) and likely variants were included in the search. For example, the following query string was used for the basic BIM+FDA string in the Scopus database as shown in Figure 1:

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TITLE-ABS-KEY ((“4d animat*” OR “4d bim” OR “4d model*” OR “4d construct*” OR “4d plan*” OR “4d schedul*” OR “4d simulat*” OR “4d visuali?ation” OR “bim” OR “building information model*” OR “construction simulat*” OR “construction digital model*” OR “construction information model*” OR “construction information requirement*” OR “schedul* visuali?ation”) AND (“claim management” OR “construction claim*” OR “construction conflict*” OR “construction delay*” OR “construction dispute*” OR “CPM schedul* delay” OR “delay analysis” OR “delay analysis method*” OR “delay analysis presentation” OR “delay analysis report*” OR “delay analysis technique*” OR “delay analysis tool*” OR “delay* dispute” OR “delay* disruption*” OR “delay* method*” OR “dispute resolution” OR “fda” OR “forensic analysis” OR “forensic claim*” OR “forensic delay analysis”))
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Figure 1. Sample query string for BIM+FDA string in the Scopus database

The next step was to remove non-English language publications and those that appeared in more than one database. This was followed by review of abstracts, omitting those not relevant. The results from this stage are shown in Table 1 which shows the SLR results including totals in each key topic area after removal of duplicates (*column vi*) and review of abstracts (*column vii*), as described above.

Table 1. Number of academic publications found in the literature including databases and filtered totals

Key Topics/ Databases	Number of publications				*column vi*	*column vii*
	Scopus	**Science Direct**	**Web of Science**	**Google Scholar**	**Totals (duplicates removed)**	**Totals (after abstract review)**
BIM + FDA	79	23	52	455	171	89
BIM + AI/ML	250	59	91	1560	595	166
FDA + AI/ML	57	15	26	75	114	35
BIM + FDA + AI/ML	0	7	0	48	48	7
Total publications	Including possible duplicates				928	296
	Total of “unique” publications				753	276

3.1. Analysis of publications before and after abstract review

3.1.1. Publication type and content of publications in the initial list. Of the 753 "unique" publications (see Table 1, *column vi*) there were 447 journal articles, 207 conference papers, 54 books, 29 theses, 8 web posts, and 8 standards or reports. Of the journal articles the majority were speculative discussions (c.70%) or reviews (c.19%), while only 49 articles (c.11%) mentioned case studies; indicating a limited degree of innovation adoption.

3.1.2. Date and location of publications in the initial list. Prior to 2006 there were very few publications (<4%) matching the search criteria. Since then there has been a steady rise and a large increase in the last four years, with over 67% between 2018 and 2021. In terms of authors' geographical location, the five most common were USA (147 publications, representing c. 20%), China (126; 17%), UK (101; 13%), Australia (43; 6%), and Canada (32; 4%).

3.1.3. Publications filtered by abstract review. A review of each abstract was made for a more detailed assessment of relevance. Removal of obvious non-relevant cases reduced the list of publications to 296 (see Table 1, *column vii*). This was subsequently further reduced (after removal of duplicates) to the 276 publications featured in Table 1, *column vii*. These abstracts were sorted according to which of the three search areas (FDA, BIM, and AI/ML) they addressed. Given the focus of the study (the potential use of BIM and/or AI/ML in FDA), particular attention was paid to publications that substantially addressed FDA **and** at least **one** of the other two search areas. The content of these publications was then assessed for examples of support or rejection of the assumed challenges and shortcomings of the current FDA process (see 2.2, above) and the potential for improvement presented by emerging technologies (see 2.3, above).

4. Findings and discussion

After their abstract review, the 276 publications (in Table 1, *column vii*) were thoroughly reviewed, and their key points (which could be supportive or contradictory to the assumptions of the research study) from these publications were extracted. The following sections provide a short summary of the findings. First, the literature supporting the rationale for an improved FDA process is considered. This is followed by discussion of the potential contribution of BIM and AI in doing so.

4.1. Improving the current FDA process

4.1.1. The need for analytical support in the FDA process. The overall aim of enhancing FDA analysis is to improve the retrieval, scrutiny, and flow of data within the FDA process. It is pointed out that effective management of the project data and successful communication of its technical aspects in construction dispute resolution processes have always been challenging tasks [20]. Similarly, Schäfer [24] supports the view that construction projects, from beginning to end, can generate vast amounts of data, typically recorded in such a dispersed manner that identifying, extracting, and understanding relevant information can be a laborious task. For many years, the Society of Construction Law [16] and the American Association of Cost Engineering [17] have aimed to provide useful guidance on the FDA process by codifying, standardising and improving the methods used by the construction industry [14]. Farrow [25] asserts that in spite of some methods are more powerful than others, there is no preferrable approach among them applicable for all cases to analyse delays. Likewise, Parry [15] believes that it is technically infeasible to adopt a formulaic approach to a delay analysis due to the complexity and the uniqueness of projects. Nevertheless, there are clear opportunities for supporting the FDA process analytically to improve the communication of data, to enable retrieval of all spatial related project documents pertaining to a specified delay event and to overcome the challenges that the delay analysts face. It is suggested that this analytical support can both improve the communication of data and allow the analysts to test the performances of different what-if scenarios for the most effective method of validating of claims [26]. Likewise, Guévremont and Hammad [27] hold the view that the analytical

support can contribute to the clarification of causality and enhance the analysis of delay responsibilities and entitlements.

4.1.2. Support for the presentation of evidence in claims and/or dispute proceedings. Claims negotiations and all dispute resolution methods listed earlier have a common requirement for the parties to present their respective cases. After thorough review of both theoretical literature and empirical research, it is revealed that there is a lack of agreement on the regulating principle that guides decision makers how to interpret the presentations and render awards [28]. However, visualisation is recognised as an effective element of such presentations. There is a consensus [29, 30] that traditional FDA evidence can be difficult to interpret due to the complexity of the technical information that, and needs to be communicated to decision-makers who have limited or no knowledge of construction sequence concepts [11]. It is recognised that visualisation is not only good for communication *within* project teams, but also for conveying technical concepts to non-technical audiences *outside* those teams [31]. This particularly relates to providing a chronological narrative of the project and any related delay events [30].

4.2. Opportunities using emerging technologies in FDA

4.2.1. Opportunities for the use of BIM. As well as its increased applications in other areas of construction, BIM has huge potential in resolving disputes [30]. To give an instance, it is argued that BIM can significantly reduce the occurrence of disputes over errors in design drawings and variations [32]. This does not preclude the occurrence of other causes of delay, however, here too, as recognised by Chou and Yang [33], BIM can solve problems encountered in FDA. Delay analysts/experts identify the top challenges of the analysis as "retrieval of information" and "clear representation of the analysis", and the potential of BIM for collection, analysis and presentation of data offers substantial support to overcome these challenges, making it a beneficial tool in analysing schedule and workspace conflicts analysis [34]. For doing this, Gibbs [11] proposes coordinated project information and n-dimensional (nD) modelling. Many researchers support this notion with case studies. One of these [35] compares the use of BIM in claims management with traditional methods and concludes that BIM outperforms traditional practices in identifying, analysing and/or demonstrating the causation, entitlement, and quantification of claims. Similarly, in another study [36], a method is introduced for measuring project delays using the elemental level of the model for their quantitative attribution and comparing the results favourably with conventional assessment methods. In a different study [37], a graphic user interface prototype was developed linking together all necessary information stored in BIM and project management software to be used as factual evidence to support a claim. This prototype was tested on a case study and resulted in an increase in overall efficiency and reduction of time spent by the analyst in retrieving relevant information. In another study [13], a system for evaluating claims by linking BIM model parameters with a centralised database of claims information was developed. Following validation by experts, it is concluded that the system can resolve most of the identified issues *"... in negotiations, arbitrations or any other dispute resolution process ... in short time with more clarity, transparency and the satisfaction of all stakeholders"*. Likewise, another study [38] presents a BIM-based FDA method to establish a factual matrix and chronology of delay events.

4.2.2. Opportunities for the use of "4D animation". Throughout the reviewed literature there is frequent use of the term "4D animation". As noted earlier, this entails linking a 3D model with a construction schedule to enable planners and project managers to visualise an animated sequence of construction activities [39, 40]. Animation technology has been used for some time to assist forensic investigations, including crime scene reconstruction [41], natural disasters [20] and structural failures [42] and has begun to be accepted in construction-related cases [43]. Early references to the potential of 4D animation for FDA highlight its potential for visual comparisons of *as-planned* vs *as-built* schedules and, by overlaying them, recording and notifying any time-, cost- and quality-related deviations [13, 30, 34, 44-

46]. This potential is exemplified in a study [47] which uses 4D models to reduce the delay analysts' subjectivity, provides an audit trail and visualises the results. Additionally, the effectiveness of 4D animation has been exemplified in a case study [48] which developed a web- and database-supported 4D animation method to track the scheduled, ongoing, delayed (late start), delayed (overdue), delayed (not start), and finished tasks for a certain period. In another example [27], a method linking delay claims with 4D simulation used visual analytics to enhance the analysis of claims representing the delay effects, causes and responsibilities. It is considered that *"a BIM model analysed in time (4D) can act like a witness because it is a large and important source of record information"* [49].

4.2.3. Opportunities for the use of Artificial Intelligence. Although every construction dispute may have unique aspects, there are certain reoccurring patterns – such as the procedures dictated by standard conditions of contract – that may suit the deployment of AI capabilities [24]. Interest in these opportunities dates back to 1991, however, the period between 2018 and 2021 has seen a marked increase in the literature. Early examples include *"a conceptual AI model for construction claims management"* that performed time impact analysis and apportionment of damages in different delay/acceleration situations [50]. Establishing delay causation was the aim of an AI-supported database [51], and a decision support system was proposed to support conflict resolution and simulate the negotiation process [52]. Another study [53] has analysed the main factors of construction delays through ML algorithms, as did Mahfouz and Kandil [54] in their development of an automated litigation outcome prediction method for differing site condition disputes. In more recent studies, automation of professional dispute resolution in construction projects using AI and blockchain technologies was discussed [55]; a neural network-long short-term memory model was developed to estimate schedule to completion accurately using time-dependent and -independent factors that were associated with delays [56]; the use of AI to avoid and resolve disputes was examined [57]; ML models were developed to facilitate accurate project delay risk analysis and prediction, and evidence-based decision making [58]; a hybrid architecture (where AI is teamed with human experts) was introduced for forensic evidence examination [59]; a two-layered fuzzy logic-based model for predicting court decisions was proposed [60]; recent advances in natural language processing (NLP) techniques were reviewed to process voluminous unstructured data from legal documents to establish root causes of disputes and subsequently, prevention strategies [61]; and a premise for using an ensemble ML algorithm for predicting project delays was presented [62]. The review indicates that AI/ML has been widely accepted in different sectors. However, in spite of its powerful capabilities (e.g., analysing voluminous, complex, and interdependent data sets of varying structure for deriving useful insights) it is still perceived as novel within the construction industry. Its practical application in FDA is limited and almost non-existent [58].

4.3. Barriers to the adoption of BIM and AI in FDA

These opportunities to improve the conventional process of FDA appear quite promising. It is pointed out that there has been a sustained increase in the adoption of technologies by the construction industry over the previous 10 years [63]. However, there are clearly barriers to adoption that account for their as-yet limited use in FDA. Some of these are familiar. They include time and cost implications [20], additional resource requirements [30], lack of in-house capabilities [23], and entrenched preferences amongst professionals (including legal professions) for conventional approaches [13, 20, 23]. In the case of BIM (and 4D), although its use has become more commonplace, particularly via the government's mandate strategies on BIM use and adoptions, in each project the degree of uniform, extensive use and adoptions of BIM differ considerably [64], resulting in more and more disputes where BIM models exist; similarly, the models have not been designed for the kind of retrospective analysis required for FDA [23]; equally, conventional FDA workflows are not geared to exploiting the technology [65]. Guevremont and Hammad [43] cite the acceptability (or otherwise) of digital documents as court evidence, the legal validity of digital models, intellectual property and model ownership issues, data interoperability and compatibility of BIM data among project stakeholders, data transfer and security, and lack of effective integration of BIM into contractual relationships. Regarding the slow adoption of

AI/ML for FDA, the extensive computational requirements, unavailability of data, ethics, data privacy, and data protection are cited [23]. Valavanoglou and Heck [30] refer to further challenges, such as a lack of hybrid experts who are familiar with BIM and AI technologies in addition to experience of FDA. They also cite the resistance to change from existing subject specialists (forensic engineers, expert witnesses, and dispute adjudicators) and limitations of existing forms of contract. Undoubtedly, among the aforementioned barriers, there are domain-specific challenges in adoption of the new approaches. However, many of them (reluctance to innovation, cost and time implications, etc.) are not unique to FDA and are common to other industries that face transformation of their existing processes. None of these advances could ever have been achieved without overcoming similar barriers. Additionally, [19] argues the role of innovative opportunities in construction projects by stating that minor changes can lead to significant savings and improvements in megaprojects, in contrast, they are mostly ignored in smaller ones; despite this, all the possibilities of opportunities must still be encouraged in any type of project.

5. Conclusions and further research

This paper describes part of a wider research project that explores the integration BIM and AI/ML technologies within the FDA process. Relevant academic publications in the subject areas of FDA, BIM, AI/ML (relating to construction) were systematically identified and reviewed. The findings indicate that emerging technologies such as BIM and AI/ML offer promising solutions to the challenges and shortcomings of the current FDA process and opportunities for enhancing the effectiveness of outputs in dispute resolution. Though recent studies show that similar technologies have been widely adopted in forensics science and partially adopted in more general processes within the construction industry, their use in FDA is rare. Only a few studies have been carried out in the integrated areas of FDA, BIM, AI/ML and none of these relate to their combined use on a real project.

Although the potential and use of digital information technologies (e.g., virtual reality and BIM-extracted visualisations) has growing acceptance in the support of forensic claims, there is still limited use of them in FDA. The reasons for this have been considered; and many of them are familiar barriers to the adoption of any new technology. However, the current data extraction process in BIM workflows can be improved, models can be more effectively managed, and eventually, these data can be communicated within an improved FDA workflow. Consequently, this potential can support the detection of causes of delays, find evidence to support claims, and even avoid the disputes in advance of delay events. In addition, and with the greater availability of appropriate digital information, the learning, inference, and predictive power of AI/ML can then be applied to considerably enhance the efficiency of the resulting FDA process.

This study lays the groundwork for future stages of the research to explore and experiment with the integration of BIM and AI/ML in the FDA process to enhance its efficiency and the effectiveness of its outputs. The initial findings show encouraging prospects for the adoption of these new technologies in FDA. Further work is needed to test the improvements on real-world project workflows and to collect expert feedback to assess their effectiveness in presenting evidence in claims and disputes.

References

[1] Oxford Economics 2021 Future of Construction [online] https://resources.oxfordeconomics.com [Accessed 28-12-2021]
[2] Hwang B-G, Ngo J and Teo J Z K 2022 Challenges and Strategies for the Adoption of Smart Technologies in the Construction Industry: The Case of Singapore *Journal of Management in Engineering* **38** 05021014
[3] Sepasgozar S M and Davis S 2018 Construction technology adoption cube: An investigation on process, factors, barriers, drivers and decision makers using NVivo and AHP analysis *Buildings* **8** 74
[4] Rivera A, Le N, Kashiwagi J and Kashiwagi D 2016 Identifying the Global Performance of the Construction Industry *Journal for the Advancement of Performance Information and Value* **8**

7
[5] Arcadis 2021 Global Construction Disputes Report [online] https://www.arcadis.com/en-gb/knowledge-hub/perspectives/global/global-construction-disputes-report [Accessed 28-12-2021]
[6] Burr A and Pickavance K 2010 The use of visualisations in case presentation and evidence *Construction Law Journal* **26** 3-17
[7] Durdyev S and Hosseini M R 2018 Causes of Delays on Construction Projects: A Comprehensive List *International Journal of Managing Projects in Business* **13** 20-46
[8] FIDIC 2017 *Construction Contract 2nd Ed. (2017 Red Book)* (Geneva: the Fédération Internationale des Ingénieurs-Conseils (FIDIC))
[9] Gebken R J and Gibson G E 2006 Quantification of costs for dispute resolution procedures in the construction industry *Journal of professional issues in engineering education and practice* **132** 264-71
[10] Kumaraswamy M M 1997 Improving industry performance through integrated training programs *Journal of Professional Issues in Engineering Education and Practice* **123** 93-7
[11] Gibbs D-J 2017 Development of building information models (BIM) to support innovative time management and delay analysis Loughborough University
[12] Vidogah W and Ndekugri I 1997 Improving management of claims: contractors' perspective *Journal of management in engineering* **13** 37-44
[13] Ali B, Zahoor H, Nasir A R, Maqsoom A, Khan R W A and Mazher K M 2020 BIM-based claims management system: A centralized information repository for extension of time claims *Automation in Construction* **110** 102937
[14] Axelson A S 2021 Let's Get Metaphysical: Mitigating the Credibility Crisis in Forensic Delay Analysis *Society of Construction Law (UK)*
[15] Parry A 2015 The improvement of delay analysis in the UK construction industry Northumbria University
[16] Society of Construction Law 2017 *Society of Construction Law Delay and Disruption Protocol* (Leicestershire: Society of Construction Law (UK))
[17] American Association of Cost Engineering 2011 *International recommended practice no. 29r-03, 'Forensic Schedule Analysis'*
[18] Gibbs D-J, Emmitt S, Ruikar K and Lord W 2014 Recommendations on the creation of computer generated exhibits for construction delay claims *Construction Law Journal* **30** 236-48
[19] Jackson S 2017 Promoting Innovation in Construction *International Construction Law Review*
[20] Soltani Z, Anderson S and Kang J 2017 The challenges of using BIM in construction dispute resolution process. *The 53rd ASC Annual International Conference Proceedings* (Seattle: Associated Schools of Construction) pp 771-6
[21] Li J, Kassem M, Ciribini A and Bolpagni M 2019 A proposed approach integrating DLT, BIM, IOT and smart contracts: Demonstration using a simulated installation task. *International Conference on Smart Infrastructure and Construction 2019 (ICSIC) Driving data-informed decision-making* (Cambridge: ICE Publishing) pp 275-82
[22] Gledson B J and Greenwood D 2017 The adoption of 4D BIM in the UK construction industry: an innovation diffusion approach *Engineering, Construction and Architectural Management* **24** 950-67
[23] Akinosho T D, Oyedele L O, Bilal M, Ajayi A O, Delgado M D, Akinade O O and Ahmed A A 2020 Deep learning in the construction industry: A review of present status and future innovations *J. Build. Eng.* **32** 14
[24] Schäfer E 2021 *Construction Arbitration and Alternative Dispute Resolution,* ed R Nazzini (Oxon and New York: Informa Law from Routledge) pp 53-8
[25] Farrow T 2001 Delay analysis—Methodology and mythology *Society of Construction Law*
[26] Hammam A and El-Said M 2018 Extension of IFC schema in construction delay claims *Journal of Al-Azhar University Engineering Sector* **13** 908-19

[27] Guévremont M and Hammad A 2021 Ontology for Linking Delay Claims with 4D Simulation to Analyze Effects-Causes and Responsibilities *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* **13** 04521024
[28] Besaiso H, Fenn P and Emsley M 2017 International construction arbitration: a need for decoding the black box of decision making *International Construction Law Review* **34** 288-308
[29] Keane P J 1994 A computer-aided systematic approach to time delay analysis for extension of time claims on construction projects Loughborough University of Technology
[30] Valavanoglou A and Heck D 2016 Building information modeling and forensic analysis of delay and disruption. *Interaction between Theory and Practice in Civil Engineering and Construction* pp 527-32
[31] Brando F, Iannitelli A, Cao L, Malsch E A, Panariello G, Abruzzo J and Pinto M J 2013 Forensic Information Modeling: A New Forensic Tool *Civil Engineering Magazine Archive* **83** 48-53
[32] Marzouk M, Othman A, Enaba M and Zaher M 2018 Using BIM to Identify Claims Early in the Construction Industry: Case Study *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* **10** 8
[33] Chou H Y and Yang J B 2017 Preliminary Evaluation of BIM-based Approaches for Schedule Delay Analysis. *IOP Conference Series: Materials Science and Engineering* 245 p 062048
[34] Jalal M P, Roushan T Y, Noorzai E and Alizadeh M 2020 A BIM-based construction claim management model for early identification and visualization of claims *Smart and Sustainable Built Environment* **10** 227-57
[35] Al Shami K 2018 Investigating the use of building information modeling (BIM) in managing construction claims *PM World Journal* **7** 1-17
[36] Zaki T, Hosny A, Abouorban H, Hosny O, Nassar K and Zahran K 2018 BIM-Based Delay Analysis: A Framework. *Building Tomorrow's Society Conference (13-16 June 2018 Fredericton, Canada),* pp 1-10
[37] Valavanoglou A, Heck D and Rebolj D 2018 A Graphical User Interface (GUI) For Forensic Analysis Of Delay and Disruption. *Proceedings of the Fourth Australasia and South-East Asia Structural Engineering and Construction Conference (3-5 Dec 2018 Brisbane),* 5 pp CON-07-1-6
[38] Marey M, Amer N and Amer A E 2020 Analysis of Delay Causes Using BIM *EasyChair* **4781**
[39] Eastman C M, Eastman C, Teicholz P, Sacks R and Liston K 2011 *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors* (New Jersey: John Wiley & Sons)
[40] Musa A, Abanda F, Oti A, Tah J and Boton C 2016 The potential of 4D modelling software systems for risk management in construction projects. *CIB World Building Congress 2016: Intelligent Built Environment for Life (30 May - 3 June 2016 Tampere, Finland),* 5 pp 988-99
[41] Buck U, Naether S, Räss B, Jackowski C and Thali M J 2013 Accident or homicide–virtual crime scene reconstruction using 3D methods *Forensic science international* **225** 75-84
[42] Karanci E and Nagata R 2013 A new method for managing and presenting façade investigation data. *Forensic Engineering 2012: Gateway to a Safer Tomorrow* pp 861-70
[43] Guevremont M and Hammad A 2020 Review and Survey of 4D Simulation Applications in Forensic Investigation of Delay Claims in Construction Projects *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* **12** 9
[44] Charehzehi A, Chai C, Yusof A M, Chong H Y and Loo S C 2017 Building information modeling in construction conflict management *International Journal of Engineering Business Management* **9** 18
[45] Zhang J P and Hu Z Z 2011 BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. Principles and methodologies *Automation in Construction* **20** 155-66
[46] Koc S and Skaik S 2014 Disputes resolution: Can BIM help overcome barriers? *CIB World Building Congress 2014: Construction in a Changing World* (University of Salford:

International Council for Building (CIB)) pp 1-15
[47] Handayani T N, Likhitruangsilp V and Yabuki N 2019 A building information modeling (BIM)-integrated system for evaluating the impact of change orders *Engineering Journal* **23** 67-90
[48] Park J, Cai H, Dunston P S and Ghasemkhani H 2017 Database-supported and web-based visualization for daily 4D BIM *J. Constr. Eng. Manage.* **143** 04017078
[49] Vacanas Y, Themistocleous K, Agapiou A and Hadjimitsis D 2015 Building Information Modelling (BIM) and Unmanned Aerial Vehicle (UAV) technologies in infrastructure construction project management and delay and disruption analysis. *Third International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2015)* 9535 pp 95350C-1-11
[50] Riad N, Arditi D and Mohammadi J 1991 A conceptual model for claim management in construction. An AI approach. *Artificial Intelligence Techniques and Applications for Civil and Structural Engineers (19-21 Sep 1989 Edinburgh),* pp 123-30
[51] Soibelman L and Kim H 2002 Data preparation process for construction knowledge generation through knowledge discovery in databases *J. Comput. Civil. Eng.* **16** 39-48
[52] Kassab M, Hipel K and Hegazy T 2008 Computerized DSS for construction conflict resolution. *Canadian Society for Civil Engineering - Annual Conference Proceedings* 1 pp 474-82
[53] Kim H, Soibelman L and Grobler F 2008 Factor selection for delay analysis using Knowledge Discovery in Databases *Automation in Construction* **17** 550-60
[54] Mahfouz T and Kandil A 2012 Litigation outcome prediction of differing site condition disputes through machine learning models *J. Comput. Civil. Eng.* **26** 298-308
[55] Barnett J and Treleaven P 2018 Algorithmic dispute resolution—The automation of professional dispute resolution using AI and blockchain technologies *The Computer Journal* **61** 399-408
[56] Cheng M-Y, Chang Y-H and Korir D 2019 Novel approach to estimating schedule to completion in construction projects using sequence and nonsequence learning *J. Constr. Eng. Manage.* **145** 04019072
[57] Catelain M 2019 How does artificial intelligence help to avoid disputes in construction? *PM World Journal* **8** 1-18
[58] Gondia A, Siam A, El-Dakhakhni W and Nassar A H 2020 Machine Learning Algorithms for Construction Projects Delay Risk Prediction *J. Constr. Eng. Manage.* **146** 16
[59] Chen J Q 2020 AI-Enabled Digital Forensic Evidence Examination. (Switzerland: Springer International Publishing) pp 832-41
[60] Bagherian-Marandi N, Ravanshadnia M and Akbarzadeh T M R 2021 Two-layered fuzzy logic-based model for predicting court decisions in construction contract disputes *Artificial Intelligence and Law* **29** 453-84
[61] Hassan F u, Le T and Lv X 2021 Addressing Legal and Contractual Matters in Construction Using Natural Language Processing: A Critical Review *J. Constr. Eng. Manage.* **147** 03121004
[62] Egwim C N, Alaka H, Toriola-Coker L O, Balogun H and Sunmola F 2021 Applied Artificial Intelligence for Predicting Construction Projects Delay *Machine Learning with Applications* **6** 100166
[63] Lemaire C, Rivest L, Boton C, Danjou C, Braesch C and Nyffenegger F 2019 Analyzing BIM topics and clusters through ten years of scientific publications *Journal of Information Technology in Construction* **24** 273-98
[64] Winfield M 2018 Drones: The Legal Frontier - the Opportunities and Risks of Taking Flight *Society of Construction Law*
[65] Greenwood D, Sanchez D, Atanasov V and Benghi C 2019 Information requirements for the use of 4D forensic delay analysis on construction projects. *35th Annual ARCOM Conference (2-4 September 2019 Leeds),* pp 326-35