Loughborough University
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Development of Building Information Models (BIM) to Support Innovative Time Management and Delay Analysis

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DEVELOPMENT OF BUILDING INFORMATION MODELS (BIM) TO SUPPORT INNOVATIVE TIME MANAGEMENT AND DELAY ANALYSIS

By

David-John Gibbs

A dissertation thesis submitted in partial fulfilment of the requirements for the award of the degree Doctor of Engineering (EngD), at Loughborough University

September 2016

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ABSTRACT

Although time is a critical factor for most projects, the majority of construction projects encounter delay. Conventional methods for managing time tend to use static medium, which can make understanding delay challenging. This can result in reactive management, which contributes to inappropriate mitigation measures, untimely and insufficient claims, and failures to award extensions of time. These consequences are common causes of dispute, which have a negative effect on the construction industry. The likelihood and severity of disputes on construction projects are increasing but it is suggested that Building Information Modelling (BIM) has the potential to reduce the number of delays and disputes in the industry. However, literature directly addressing how to achieve this appears limited.

To contribute research to this knowledge gap, this EngD aims to improve the understanding of delay on construction projects through BIM. This is addressed through five objectives, which gather data through a case study, workshop, simulation, questionnaire, focus group, content analysis and the available literature. The findings of each objective contribute to the next stage of research and led to the proposed interactive exhibit, which integrates VARK modes of presentation with 4D modelling technology developed to support BIM. The rationale behind this proposal is supported by five journal publications, which are appended to this document.

The research concludes that the interactive exhibit offers greatest value to individuals who have limited experience of the construction project, leaning the application of the proposed concept towards dispute resolution. This finding is consistent with existing literature, which identifies the challenge of creating a holistic tool for both pro-active management and retrospective analysis. Further research is being undertaken by the researcher to consider how VARK modes of presentation could be integrated with technology, such as virtual reality, to better support pro-active time management. These applications could be expanded to other areas of construction but when access to BIM project data is more widely available, there would be value in exploring the opportunity for BIM to assist with the storage and retrieval of delay information.

KEY WORDS

4D; BIM; Claim; Contracts; Delay; Dispute Resolution; Modes of Presentation; Time Management; Visualisation.

PREFACE

The research presented within this thesis was conducted to fulfil the requirements of an Engineering Doctorate (EngD) at the Centre for Innovative and Collaborative Construction Engineering (CICE), Loughborough University.

The EngD programme is more vocationally orientated than the traditional PhD and requires the Research Engineer (RE) to pursue research whilst based within a company. The research is identified by an industrial sponsoring organisation and aims to solve one or more significant or challenging engineering problems.

The EngD is examined on the basis of a thesis containing at least three (but no more than five) research publications and/or technical reports. This thesis is supported by five journal publications, which are located in Appendices A to E.

ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional
AEDM	Architectural Engineering and Design Management
BIM	Building Information Modelling
CAD	Computer Aided Drafting/Design
CDE	Common Data Environment
CGE	Computer Generated Exhibit
CGI	Computer Generated Imagery
CIOB	Chartered Institution of Building
CPC	Complex Projects Contract
CPM	Critical Path Method
EngD	Engineering Doctorate
ICE	Institution of Civil Engineers
IFC	Industry Foundation Classes
IT	Information Technology
ITCon	Information Technology in Construction
JCT	Joint Contracts Tribunal
LoB	Line of Balance
LoD	Level of Development
LSM	Linear Scheduling Method
nD	Multi-dimensional
NBS	National Building Specification
NEC	New Engineering Contract
PAS	Publicly Available Specification
PERT	Program Evaluation and Review Technique
PPC	Project Partnering Contract
RE	Research Engineer

RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SCL	Society of Construction Law
SMART	Specific, Measurable, Assignable, Realistic and Time related
UK	United Kingdom
US	United States
VARK	Visual, Aural, Read/Write and Kinesthetic
VPM	Vertical Production Method

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LIST OF PUBLICATIONS

Throughout this research project, eight publications were produced and another one is pending, but only a maximum of five peer reviewed publications can support an EngD thesis. These publications are listed below.

Supporting the thesis

Journal Paper 1 (Appendix A)

Gibbs, D., Emmitt, S., Ruikar, K. and Lord, W. (2013). An Investigation into whether Building Information Modelling (BIM) can Assist with Construction Delay Claims. *International Journal of 3-D Information Modeling*, 2(1), pp.45-52.

Journal Paper 2 (Appendix B)

Gibbs, D., Lord, W., Emmitt, S. and Ruikar, K. (2015). Building Information Modelling. *Construction Law Journal*, 31(3), pp.167-179.

Journal Paper 3 (Appendix C)

Gibbs, D., Emmitt, S., Lord, W. and Ruikar, K. (2015). BIM and Construction Contracts - CPC 2013's Approach. *Proceedings of the ICE - Management, Procurement and Law*, 168(6), pp.285-293.

Journal Paper 4 (Appendix D)

Gibbs, D., Emmitt, S., Ruikar, K. and Lord, W. (2014). Recommendations on the Creation of Computer Generated Exhibits for Construction Delay Claims. *Construction Law Journal*, 30(4), pp.236-248.

Journal Paper 5 (Appendix E)

Gibbs, D., Lord, W., Emmitt, S. and Ruikar, K. (2016). Interactive Exhibit to Assist with Understanding Project delays. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, pp.04516008-1-04516008-12.

Additional publications

Conference paper

Gibbs, D., Emmitt, S., Ruikar, K. and Lord, W. (2012). An Investigation into whether Building Information Modelling (BIM) can Assist with Construction Delay Claims. In: D. Greenwood, ed. *First UK Academic Conference on BIM, Newcastle*, *5-9 September, 2012*. England: BIM Academy, pp.36-44.

Conference paper

Gibbs, D., Emmitt, S., Ruikar, K. and Lord, W. (2013). A Case Study Investigation into the use of Computer Generated Visualisations to Assist with Construction Delay Claims. In: S. Kajewski, K. Manley and K. Hampton, eds. *Proceeding of the 19th International CIB World Building Congress, Brisbane, 5-9 May, 2013*. Brisbane: Queensland University of Technology.

Book contribution

Gibbs, D. (2016). Building Information Modelling. *In*: A. Burr, ed. *Delay and Disruption in Construction Contracts*. 5th ed. Oxon: Informa Law from Routledge, 2016, pp.573-584.

Pending Book Contribution

Gibbs, D. (2017). Building Information Modelling. *In*: CIOB (Chartered Institution of Building). *Guide to Good Practice in the Management of Time in Construction and Engineering Projects - Dynamic Scheduling*. Chichester: Wiley and Blackwell, 2017.

CHAPTER 1 INTRODUCTION

This chapter introduces the research project and demonstrates the need for research. It also discusses the scope of the research and presents the tasks undertaken to achieve the objectives and overarching research aim.

1.1 BACKGROUND

By 2030, an additional 1.2 billion city dwellers[1] are expected to inhabit the world (UN, 2015). These new inhabitants will require a built environment and the construction industry will be called upon to deliver it. To achieve this, the industry must operate efficiently but over the past 100 years, numerous publications have identified the inefficiencies of the construction industry in the UK (Latham, 1994; Egan, 1998; Farmer, 2017) and around the world (National Academies, 2009; Wold Economic Forum, 2016; McKinsey, 2017). This has resulted in various initiatives and reports, which have generated some improvement, but the rate of change has not been enough to deliver the required future demand (HM Government, 2013).

Digital technology has been identified as an enabler for this change (HM Government, 2015). Although digital technology does not replace the workforce's ability to get the job done, it does offer the potential to improve time, cost and quality deliverables. Consequently, digital technology has become a common feature on construction projects (JBKnowledge, 2015) and is pushing the boundaries of engineering, resulting in more complex design and construction. However, to match this rate of development and harness the full value of digital technology, new skills, process and strategies need to be researched and developed, in both industry and academia (CIC, 2014).

An initiative to provide meaningful research and bridge the gap between academia and industry is the Engineering Doctorate (EngD) programme, which aims to address a broad spectrum of challenges faced by the construction industry. The EngD achieves this by undertaking academic research in an industrial setting, in order to provide practical solutions to real life problems. The EngD programme is promoted by the United Kingdom's (UK) Engineering and Physical Science Research Council (EPSRC), who part sponsor a Research Engineer (RE) to investigate a problem faced by an industrial sponsor.

1.2 THE RESEARCH ENGINEER

Prior to starting the EngD, the RE obtained a Master's Degree in Civil Engineering from the University of Nottingham. Whilst studying, the RE obtained sponsorship from a transportation and infrastructure

[1] Estimated population of Africa in 2015 was 1.2 billion.

contractor and gained full time practical experience during summer vacations. On completion of the degree, the RE joined the contractor's graduate scheme and worked for one year supervising specialist surface treatment works and working in the organisation's business improvement team.

Through practical experience, the RE gained an appreciation of the methods, difficulties and importance of planning, monitoring and controlling construction works but the opportunity to improve practice through research and development was restricted. This emphasised the RE's desire to undertake meaningful postgraduate research in construction management and led the RE to embark on the EngD.

Whilst undertaking the EngD, the RE has worked with delay analysts on manufacturing, civil and building projects with individual values exceeding US$1bn. The RE has produced BIM proposals for project management teams, which has been supported through BIM Accredited Professional and Project Information Manager and Task Information Manager qualifications. The RE has also worked for a leading 4D modelling consultancy, providing innovative 4D modelling and Virtual Reality (VR) solutions to some of the UK's largest BIM projects.

1.3 THE INDUSTRIAL SPONSOR

The research project is part sponsored by DAQS Ltd, which comprises of a team of four expert consultants working from offices in Nottingham. DAQS specialises in the management of time and cost on construction projects, as well as providing expert forensic analysis on the causes and consequences of delay and quantum claims and disputes.

DAQS prides itself on using electronic information to monitor, control and assess construction works, something that is not always undertaken or well performed in the construction industry. This has led DAQS to develop bespoke, innovative, data management systems that can assist their clients with inputting, retrieving, assessing and presenting project information.

To enhance the research project, additional experience was gained by subcontracting the RE's services to Hill International. Like DAQS, Hill International provides project management and dispute resolution services for the construction industry to clients around the globe. Hill International employs over 4,800 professionals in 100 offices worldwide and is involved in some of the world's most iconic construction projects.

1.4 THE NEED FOR RESEARCH

1.4.1 INDUSTRIAL SPONSOR

DAQS witnesses the negative effects of disputes in their everyday involvement with contentious construction issues. The majority of disputes that DAQS has worked on have required a delay analysis. The delay analysts at DAQS identify delay analysis as a complex process which is made challenging by inadequate records and the need to communicate technical findings to individuals with limited construction experience. To help address these challenges, DAQS has developed processes and bespoke software to perform their tasks.

Through continual research and development, DAQS organisation became aware of BIM and its potential to reduce delay and disputes on construction projects. Given the importance DAQS places on utilising electronic information for managing and assessing construction projects, they were eager to develop BIM expertise that could support and expand their existing services. As there was little published research on utilising BIM to manage and assess delay, it was envisaged that BIM expertise could be used to promote the company profile and provide DAQS with an advantage over their competitors.

Like DAQS, Hill International understood the potential of BIM to support the management of time and analysis of delay. Recognising a gap in the market for these services and anticipating an increase in BIM adoption around the world, Hill International appreciated the importance of knowing more about the potential of BIM within their portfolio of services.

1.4.2 WIDER INDUSTRY

Time, cost, quality and scope are components of any project. Once the priorities for each of these four components are agreed, decision making becomes constrained (Figure 1-1) and a change to any one component can affect all of the other components. For example, if the project's scope is increased but the quality is required to remain the same, it could cause the project duration (time) and budget (cost) to increase (Figure 1-2).

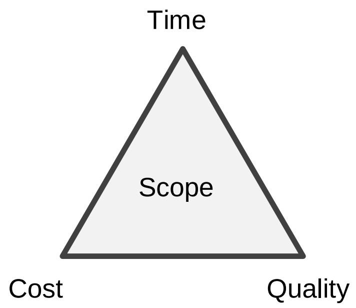

Figure 1-1: The iron triangle

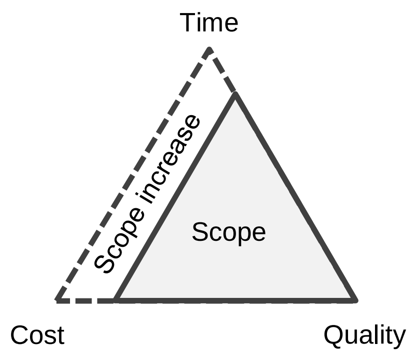

Figure 1-2: The iron triangle with scope increase

Because change is inevitable on any project, it is likely that there will be a trade-off between these various components (OGC, 2009). Although a change event will not always have a negative consequence, change should be managed pro-actively to improve understanding about its effect and to allow for appropriate mitigation efforts.

If a change event adversely effects a project team member and its cause is not the effected party's risk or responsibility, the effected party is entitled to claim compensation to return them to the position they would have been if the change had not occurred (Haidar, 2011). Therefore, the inevitability of change on a project makes claims an inherent and necessary part of construction (Kumaraswamy, 1997).

Although it may be simple for a claim to originate, communicating and agreeing the effect of change can be challenging because of the complex interfaces that exist between the numerous work activities on construction projects. As a consequence, a claim may not be admitted, which could cause a dispute to arise (*AMEC v. Secretary of State for Transport*).

The global average construction dispute costs US$51.1 million, lasts 13.2 months (Arcadis, 2015) and generates indirect costs of lost productivity, stress and fatigue, loss of future work, reduced profit and tarnished reputation (Love, 2010).

The number of disputes in the construction industry are expected to rise (NBS, 2015a) and two of the common causes of dispute are (Arcadis, 2015):

1. Failure to make interim awards on extensions of time and compensation; and,
2. Poorly drafted or incomplete and unsubstantiated claims.

This is pertinent with research that identified that over 60% of complex construction projects overrun on time and budget (NAO, 2001; CIOB, 2008). Within these projects, it was found that the schedules were often inadequate; time related information was usually poorly recorded and managed; and, technology was rarely used to its full potential. Overall, conventional tools and processes for time management were found to have not developed much since their creation a 100 years ago and were insufficient for the increasingly complex projects of today. Therefore, a step change is required.

The core documents developed to support the UK Government's BIM mandate stated that BIM has the potential to reduce the number of delays and disputes on construction projects (BSI, 2013). BIM has the potential to address these challenges through the promotion of collaborative working practices and the use of technology to improve the generation, management and communication of information throughout an assets lifecycle (Cabinet Office, 2011).

However, time management is not the primary objective of BIM. As a consequence, a connection between BIM and delay analysis, particularly in relation to construction disputes, appeared absent in the literature and industry. Therefore, to fill this knowledge gap, research into how BIM could reduce the likelihood and severity of construction delay disputes was required.

1.5 RESEARCH SCOPE

The initial research scope sought to investigate BIM and the management and analysis of delay. This was undertaken early in the project through a review of the literature and practical experience within the sponsoring organisation. However, as the research developed, it became clear that additional topics needed to be considered in order to provide a holistic solution to better understand delay, so the research scope was extended to include technology and disputes (Figure 1-3).

As the research advanced, the scope narrowed but these four topics remained at the core of the project. The link between these topics is presented in the literature review (Chapter 2).

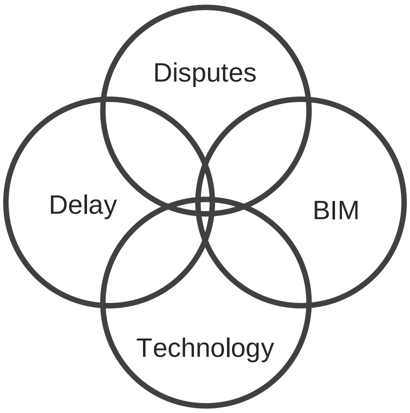

Figure 1-3: Scope of the research project

1.6 AIM AND OBJECTIVES

The aim of this research project is to improve the understanding of delay on construction projects through BIM.

To achieve this aim, the following five objectives are undertaken.

1. Review related work to understand the challenges of analysing delay and the current application of BIM in the construction industry;
2. Explore the legal implications of using BIM through an analysis of standard forms of construction contract;
3. Investigate how the visual capabilities of BIM are being used to improve understanding about delay;
4. Develop an innovative solution to manage and analyse delay with BIM; and,
5. Validate the proposed concept through industry expert opinion.

These five objectives follow a logical approach, which identify and understand the research problem, explore and develop a solution, and then validate the findings (Chapter 3).

1.6.1 RESEARCH TASKS

To achieve the overarching research aim, each of the five objectives were assigned Specific, Measurable, Assignable, Realistic and Time related (SMART) tasks (Table 1-1).

Table 1-1: SMART tasks to accomplish research objectives

Objective	Specific	Measurable	Assignable	Realistic	Time related
1	Undertake a detailed literature review to understand how delay is analysed and managed; the challenges faced by delay analysts; and, the potential to address these challenges.	Write up the findings and submit for peer reviewed publication.	Research and write up findings alone, with publication support from academic staff.	Focus the first year of the project towards this exploratory phase of research.	Submit for publication in 2012 and continually update the findings as the research project progresses.
2	Undertake a content analysis to investigate how standard forms of contract attempt to facilitate a BIM environment by addressing the perceived barriers of BIM adoption.	Disseminate findings in industry presentations and training sessions, then refine and write up for a peer reviewed publication.	Obtain information on BIM and contracts, and write up findings with publication support from academic staff.	Build on Objective 1 and integrate with practical work undertaken with industrial sponsor.	Present findings at CIOB conference in September 2013 and submit paper for publication by end of 2014
3	Analyse case studies to determine how visualisations have been used to assist construction claims and investigate the application of software, which has been developed to support BIM, for construction claim purposes.	Write up the findings and submit for peer reviewed publication.	Gather information from delay claim that used visualisations and analyse and write up the findings with publication support from academic supervisors.	Build on Objective 1 as part of dedicated EngD research.	Submit for publication in October 2012.
4	Develop a solution that can assist the understanding of complex delay.	Write up the findings and submit for peer reviewed publication.	Obtain case study data from industry experts, develop and report the findings with publication support from academic supervisors.	Build on Objective 1 and Objective 3 as part of dedicated EngD research.	Submit for publication before the end of the EngD.
5	Gather data from industry experts to determine the value of the proposed solution for pro-active time management and retrospective analysis.	Include findings in the thesis.	Gather opinion from industry experts and report the findings.	Validate the proposed solution in Objective 4 as part of dedicated EngD research.	Submit as part of EngD thesis.

1.7 STRUCTURE OF THE THESIS

Throughout this thesis, the research objectives are used as a framework to report the research findings. The research is presented across five chapters, each consisting of various subsections, and an appendices comprising of five journal papers. A short description of each chapter is provided below.

Chapter 1 introduces the research project and presents the need for research. It discusses the scope of the research and states the tasks undertaken to achieve the objectives and overarching project aim.

Chapter 2 reviews the literature related to the project scope to identify knowledge gaps and research opportunities.

Chapter 3 presents the methodological considerations underpinning the research project and explains the methods adopted to address each of the research objectives.

Chapter 4 demonstrates the research undertaken to satisfy each research objective and fulfil the overarching project aim.

Chapter 5 summarises the key research findings, identifies their implications and the original contributions to knowledge. A critical evaluation is provided and recommendations for future work are presented.

Appendices include five published journal papers that support the research project. Journal formatting has been removed for consistency.

CHAPTER 2 REVIEW OF RELATED LITERATURE

This chapter presents a literature review of the topics identified in the research scope (Section 1.5). The connection between each of these topics is presented and knowledge gaps that would benefit from further investigation are identified. Additional information on these topics can be found in the appended papers, which are cross-referenced throughout this chapter.

2.1 DELAY

Literature relating to the topics of delay are included in all of the appended papers. This section provides a broad overview of published guidance on managing time and analysing delay on construction projects.

The literature states that delay on construction projects can be divided into the following two categories (SCL, 2002):

1. **delay to progress:** a delay to the start and/or finish of an activity, which does not cause a delay to completion; or,
2. **delay to completion:** a failure to complete the works, or section, by an agreed date.

Both of these categories can be caused by a “delay event”, which might be the risk of the client or the contractor. As every construction project is unique, delay events can occur for a variety of reasons (Ramanathan, 2012) but their cause can be broadly attributed to change. Change can be defined as the addition, deletion or other revision to the project goals and scope (Ibbs, 2001). If nothing were to change on a project, it would be delivered as planned. Although change can sometimes be positive, it often effects a project negatively (Dvir, 2004); therefore, because change is inevitable on any project (OGC, 2009), it needs to be managed (Lazarus, 2001).

2.1.1 MANAGING TIME

There is no consistency of approach as to how different standard forms of construction contract manage time (Pickavance, 2007a). Some contracts, such as the JCT Minor Works Building Contract, do not include any formalised process for managing time. However, most construction contracts require the production of a schedule, also referred to as a programme, to show how the works are intended to be carried out. There are a variety of scheduling techniques available and their effectiveness for time management purposes can depend on the complexity of the project (Cooke, 2009). Some of the available techniques, alongside their most suited project type, are presented in Table 2-1.

Table 2-1: Scheduling techniques for different project types (adapted from Yamín, 2001)

	Type of project	Scheduling technique	Main characteristics
Repetitive	Linear and continuous projects (pipelines, railroads, tunnels, highways)	LSM	• Few activities • Executed along a linear path/space • Hard sequence logic • Work continuity crucial for effective performance
	Multiunit repetitive projects (housing complex, buildings)	LoB	• Final product a group of similar units • Same activities during all projects • Balance between different activities achieved to reach objective production
	High-rise buildings	LoB, VPM	• Repetitive activities • Hard logic for some activities, soft for others • Large amount of activities • Every floor considered a production unit
Discrete	Refineries and other very complex projects	PERT/CPM	• Extremely large number of activities • Complex design • Activities discrete in nature • Crucial to keep project on critical path
	Simple projects (of any kind)	Bar/Gantt chart	• Indicates only time dimension (when to start and end activities) • Relatively few activities

The project types presented in Table 2-1 are divided into the following two broad categories (Cole, 1991):

1. Repetitive tasks; or,
2. Discrete tasks.

Projects that consist of repetitive tasks can benefit from techniques that seek to optimise productivity (Arditi, 1986). The repetitive scheduling techniques[2] presented in Table 2-1, provide a way of visualising task productivity and continuity by plotting activities as lines with constant or changing slopes against two axes, distance and time (Mattila, 1998; Ioannou, 2016) (Figure 2-1). The slopes represent the

[2] Linear Scheduling Method (LSM), Line of Balance (LoB) and Vertical Production Method (VPM).

production rate of each activity and can be modified, along with start and finish times, to assist with balancing resources (Chrzanowski, 1986). Some individuals favour this technique for its clear graphical format, which can be easily modified to achieve a smooth flow of work (Mattila, 2003). However, several challenges have restricted the uptake of linear scheduling techniques in the industry, of which the most notable challenge is the techniques limited application for non-repetitive works (Lutz, 1993; Arditi, 2002).

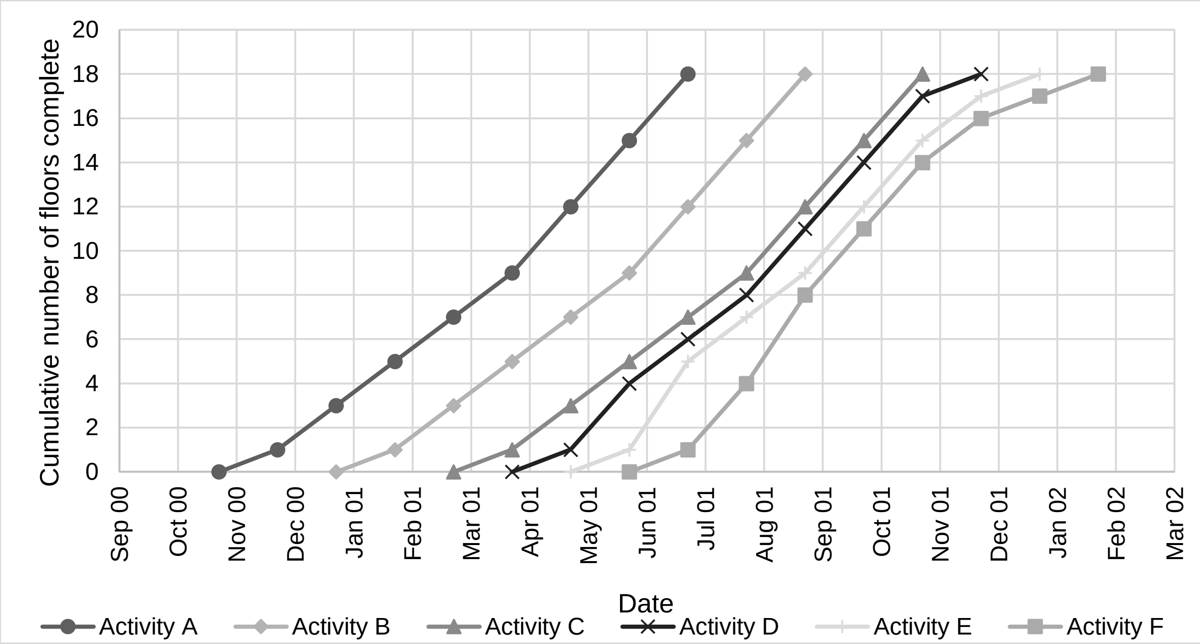

Figure 2-1: Linear scheduling technique

Projects that consist of discrete tasks[3] tend to develop the construction schedule by identifying all of the activities required to bring the project to fruition and then assigning each activity a duration based on the available resources.[4] Each activity is assumed to have a primary location due to physical and time constraints (Cole, 1991) and the construction sequence is graphically presented using time on the horizontal axis and activities on the vertical axis (Figure 2-2).

[3] Program Evaluation and Review Technique (PERT), Critical Path Method (CPM), Bar/Gantt chart.

[4] Resources are anything necessary for the achievement of the works and include labour, plant, money and materials. Space and time can also be viewed as resources (CIOB, 2011).

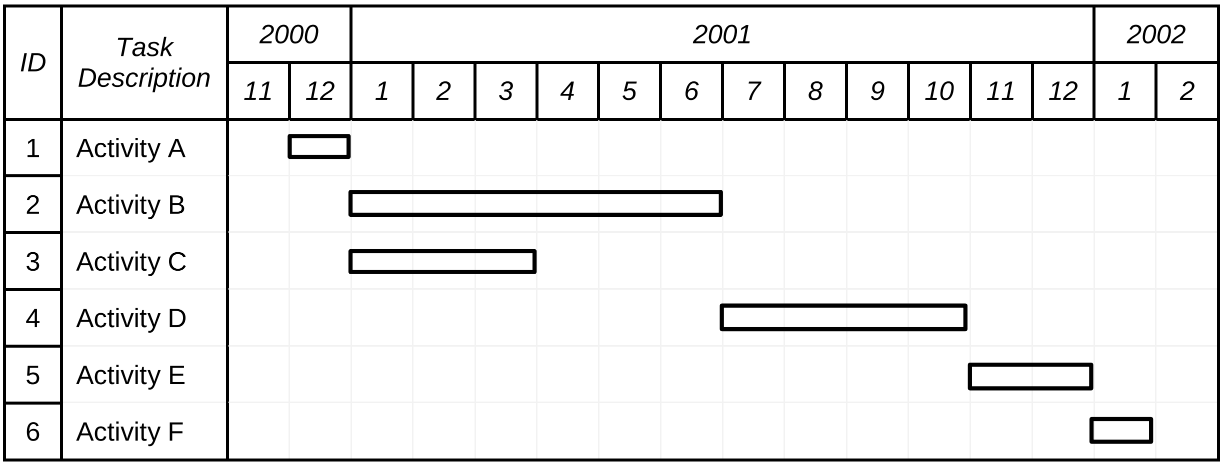

Figure 2-2: Basic Gantt chart

This is referred to as a Gantt chart, sometimes as a bar chart, which is favoured for its simplicity in communicating information. The advent of the computer made the production of Gantt charts easier and their presentation clearer (Wilson, 2003) but, in its most basic form, a Gantt chart does not include the interrelationship between activities. This can make monitoring and controlling a project cumbersome, so it is recommended that basic Gantt charts are not used for managing complex projects

Attempts to address the limitations associated with the basic Gantt chart led to the development of network models, such as the linked bar chart, and probabilistic techniques such as PERT (Harris, 2013). However, the most widely adopted network scheduling technique is reported to be the Critical Path Method (CPM) (Yamín, 2001; Ammar, 2013).

CPM uses mathematics to calculate the “critical” activities to complete a project (Kelley, 1961). If any activity on the critical path is delayed, it will extend the duration of a project. Owing to the amount of change a project will encounter, it is likely the critical activities will alter throughout a project (Whatley, 2014).

The original format of the CPM was the activity-on-arrow diagram method (Kelley, 1959) but the reliance on computers to perform this task, at a time when access to computers was limited, led to the development of the precedence-diagram method (Fondahl, 1962). The precedence-diagram method, also termed activity-on-node, considers the earliest and latest start and finish times, as well as the duration and float[5] for each activity (Figure 2-3). The method can be undertaken without the use of a

[5] Float is the unallocated time in a critical path network, which can be further divided into the following two categories (Burr, 2016). The time by which an activity may be delayed or extended without affecting the start of any succeeding activity (free float); or, the time by which an activity may be delayed or extended without affecting the total project duration (total float) (BSI, 2000).

computer but the approach remains the method adopted by most scheduling software packages (CIOB, 2011). These scheduling software packages were developed to assist with accurately processing and analysing large amounts of data, which are prevalent on complex projects, and provide the opportunity for the effect of change to be scientifically calculated faster than hand calculation (CIOB, 2011). However, without training, the precedence-diagram can be difficult to understand, so software has been developed to convert the data into Gantt charts, which assists the user's interpretation through visual presentation (Wilson, 2003).

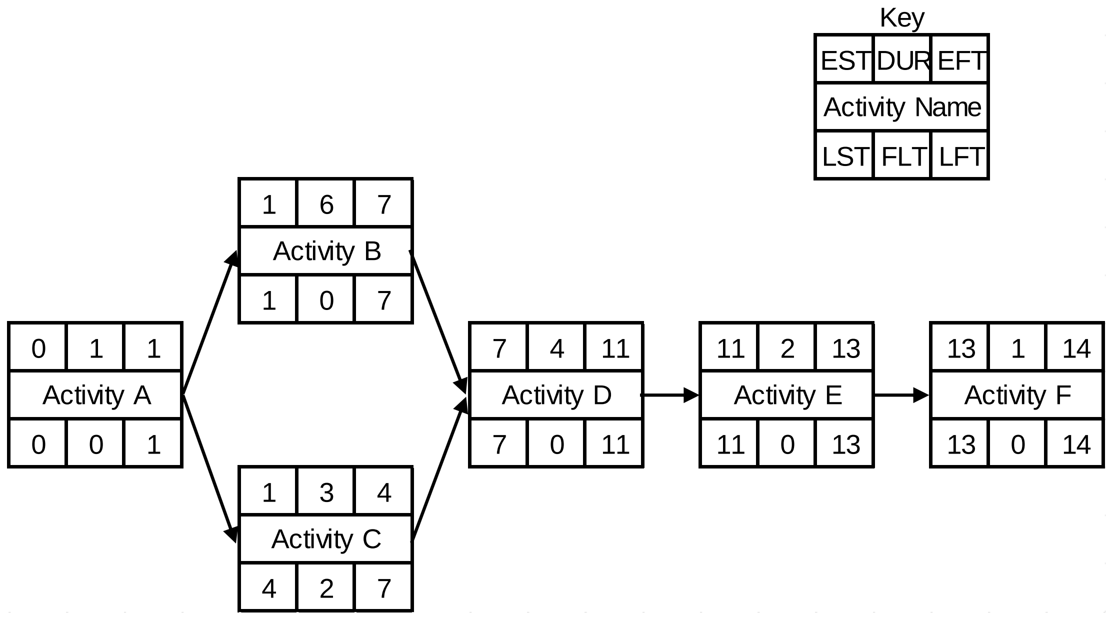

Figure 2-3: Precedence-diagram[6]

To create an effective CPM, it is recommended that consideration is given to necessity items (Farzad Moosavi, 2014) but the amount of information contained within these criteria can generate confusion, especially for repetitive work (Yamín, 2001). Furthermore, the CPM does not illustrate the position of the works, so authors of CPM networks tend to list the work's location in the activity description. Collectively, these limitations can result in lengthy, unclear, schedules that can become too confusing for the project team to use (Chrzanowski, 1986).

Therefore, when choosing a scheduling technique, consideration should be given to the best way to communicate the time related information (Mawdesley, 1997). The majority of scheduling techniques use visual methods to improve communication but it is rare for a single scheduling technique to be used to its full potential (Cole, 1991). As most construction contracts include aspects of discrete and repetitive

[6] Earliest Start Time (EST); Duration (DUR); Earliest Finish Time (EFT); Latest Start Time (LST); Float (FLT); Latest Finish Time (LFT).

works, multiple techniques could be used to complement each other (Ammar, 2013). However, clearly presenting a combination of activity based techniques and location based techniques in one medium was challenging (Jongeling, 2007) until recent developments in technology (Section 2.4.1).

Regardless of the scheduling technique adopted, to manage time effectively on a construction project, the schedule should be kept up to date and a pro-active approach to management is recommended (Love, 2002). This involves forecasting problems and taking appropriate control action to avoid or manage potential issues (Mawdesley, 1997). Once a baseline is established, for time management purposes, this resembles a cyclical process (Figure 2-4) that should be repeated as more accurate and detailed information becomes available on the project.

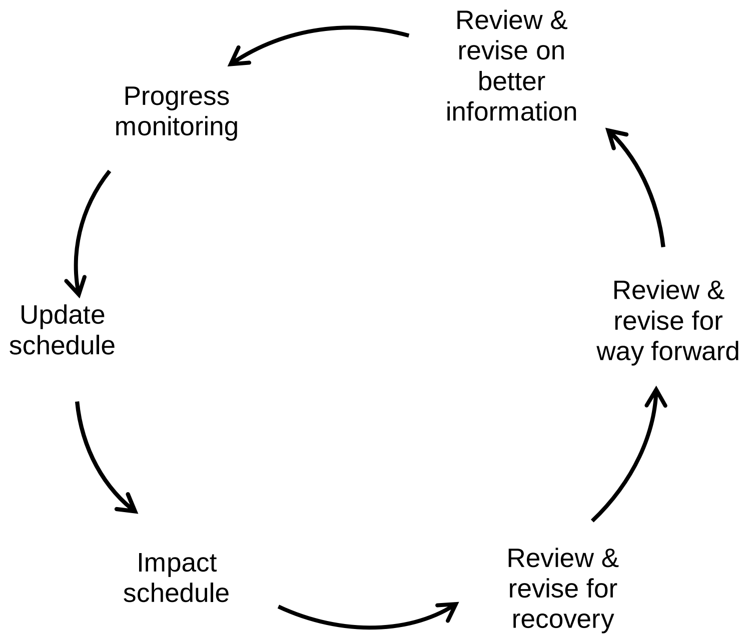

Figure 2-4: Pro-active process for managing time (adapted from CIOB, 2011)

For efficiency and accuracy, progress information should be recorded in a suitable format and identify what work was carried out, where, when and by whom. This could be captured in diaries, minutes of meetings, day work sheets, photographs and progress reports (Scott, 1990). It is suggested that this information is stored electronically to assist access, sorting, filtering and reporting (CIOB, 2011) but before this information can be used to manage time, it must be analysed to understand the effect on the project.

2.1.2 ANALYSING DELAY

Delay can be analysed prospectively or retrospectively. Literature on performing delay analysis is widely reported and included in the appended papers (Paper 1, Appendix A; Paper 5, Appendix E), but two commonly referred to guides have emerged.

Firstly, the Society of Construction Law's (SCL) Delay and Disruption Protocol (SCL, 2002), which aims to reduce disputes by providing guidance on core principles relating to delay; preparing and maintaining schedules and records; prospective assessment of delay; and, retrospective assessment of delay (Pickavance, 2004). It is reported that the SCL Protocol is clearly and logically laid out, and written in a language that non-experts can understand, which includes lawyers and judges (Bailey, 2014).

The SCL Protocol (2002) stated a preference for the time impact analysis, asserting that it is most thorough for complex disputes, despite recognising it as the most time consuming and costly delay methodology. However, industry professionals appear split over a methodology preference (Critchlow, 2006). Furthermore, the guidance on preparing and updating the schedule, along with the recommended record keeping, was criticised for being impractical, especially for smaller projects, as the costs could be proportionately higher than those incurred by larger projects. Some delay experts also argue that the protocol has become a tool for dispute resolution, which has promoted an increase in disputes, encouraging the postponement of assessing delay and increasing the cost of dispute resolution (Barry, 2013). As a consequence, the SCL Protocol (2002) has not been widely adopted by the industry (Bailey, 2014).

This prompted a review of the SCL Protocol (2002) and resulted in the publication of Rider 1, which attempts to address some of the inherent issues (SCL, 2015). Rider 1 maintains that delay claims should be submitted pro-actively but preference towards the time impact analysis, or any other methodology, has been removed (SCL, 2015).

As a single method of delay analysis has not been adopted by the industry, contracts, or the courts, (Lifschitz, 2009), Rider 1 recommends that consideration should be given to the following seven points when selecting a delay analysis methodology (SCL, 2015).

1. The relevant conditions of contract;
2. The nature of the causative events;
3. The value of the project or dispute (proportionality);
4. The time available;
5. The nature, extent and quality of the records available;
6. The nature, extent and quality of the schedule information available; and,
7. The forum in which the assessment is being made

Secondly, a separate guide was produced by the Association for the Advancement of Cost Engineers (AACE, 2007) on the recommended practice for forensic schedule analysis. The AACE guide focuses on retrospective forensic delay analysis, which uses science or technology to investigate how a project was to be constructed, the duration and relationships between activities, and the issues that caused the project to deviate (Farrow, 2001). The guide identifies a variety of delay analysis methodologies and the plethora of titles associated with each of them. The aim of the guide is to reduce the ambiguity surrounding delay analysis by defining terminology, identifying and classifying methodologies, and providing recommended practice on using the techniques.

The AACE guide has been criticised for not considering the law, not ranking the methodologies, and having a taxonomy that is too rigid and complex (D'Onofrio, 2010). As a consequence, it can be argued that the guide does not fulfil the requirements of best practice because a preferred method is not presented. Furthermore, many of the methodology names are inconsistent with the law and unfamiliar with the industry, adding further confusion to the subject area (Lifschitz, 2009).

Nevertheless, both of these guides suggest using a construction schedule to analyse delay. However, the literature demonstrates that different delay methodologies can yield different results, even when the same information is used (Braimah, 2013). Furthermore, the same delay methodology can produce diverse results if approached in a different way, such as prospectively or retrospectively, so it is recommended that the findings are judged with common sense (*Walter Lilly v. Mackay*). Otherwise, the findings of the delay analysis could be disputed.

2.2 CLAIMS AND DISPUTES

A review of claim and dispute literature is covered in all of the appended papers. This section provides context of how disputes occur and the requirements and challenges associated with construction claims.

Disputes can occur for a multitude of reasons and can result in an array of direct and indirect costs (Section 1.4.2). To address the lengthy and costly process of litigation and arbitration, a variety of alternative dispute resolution techniques have been developed (Wright, 2011). Although there is not a definitive meaning of the term dispute (Reid, 2007), it is often argued that a dispute cannot exist until a claim has been submitted and rejected (*Halki v. Sopex*).

2.2.1 CLAIM REQUIREMENTS AND CHALLENGES

Following the breach of contract, an innocent party has the right to claim damages to put them back so far as monetary possible to the position they would have been if an event had not occurred (*Robinson v. Harman*). For delay, this can be achieved through liquidated damages or general damages.

Liquidated damages are a fixed monetary sum that is included in the contract to remove uncertainty and avoid the need to prove loss (Eggleston, 2009). The amount should be a genuine pre-estimate of the likely loss and not a penalty (*Regional Construction v. Chung Syn Kheng*). In construction, liquidated damage clauses are a common component of most construction contracts and can apply when a party does not complete their works by a due date.

Conversely, general damages are assessed after the contract is breached and can only be recovered with proof of loss (Eggleston, 2009). Usually, general damages should be assessed close to when an event occurred (*Miliangos v. George Frank*) and consider remoteness, that the consequence of the event could not be foreseen (*Hadley v. Baxendale*), as well as the measure of damages, which relates to the quantum of the claim.

Different forms of damages can be claimed when delay occurs on construction projects, which will depend on how the delay event is classified. This is presented graphically in Figure 2-5 and the different categories of delay are explained in detail in Paper 1 (Appendix A).

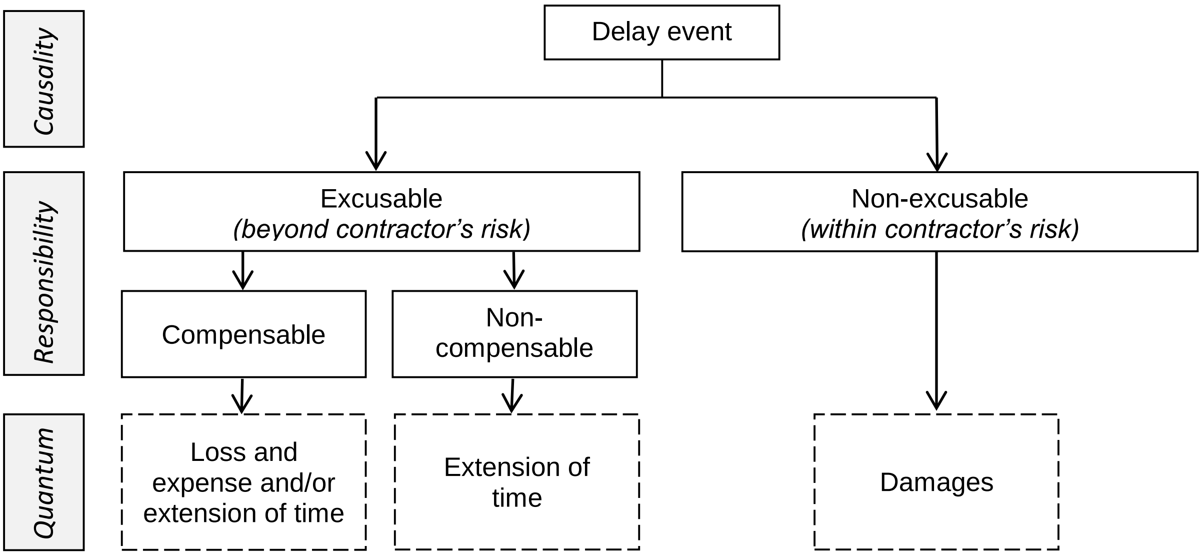

Figure 2-5: Generalised interpretation of the categories of delay (adapted from Trauner, 2009)

If a delay event is beyond the contractor's risk, they are entitled to receive an extension of time. An extension of time allows the employer to set a new completion date. This provides the employer with a mechanism to address the prevention principle, which aligns with the principle that no party may benefit from its own breach (Comyns, 1822).

Owing to the complexity of construction projects, items such as concurrency (Mastrandrea, 2014) and float ownership (Keane, 2008; Householder, 1990) can make categorising and analysing delay difficult. Furthermore, despite the availability of software to assist with time management, the process of record keeping is not always well performed in the construction industry (Kangari, 1995; Conlin, 1997) and some contemporaneous records suitable for managing the project might not be appropriate for forensic investigation (AACE, 2007). Therefore, to understand what happened on a project, delay analysts often face the challenge of retrieving records, as well as the challenge of communicating their findings to individuals who have not been practically involved in the project, such as lawyers or judges (Paper 1, Appendix A).

The burden of proof lies with the claiming party but it can transfer to the defending party if there is sufficient evidence of a valid claim. The standard of proof will be judged on the balance of probabilities, that an event is more likely to have occurred than not, and will be influenced by the factual evidence and how it is presented, with stronger evidence required for more serious allegations (Haidar, 2011).

Contemporaneous evidence is preferred and the delay analysis must prove breach, causality, responsibility and quantum (Williams, 2003a). The legal system leans towards the use of construction schedules, particularly the use of the critical path method, for analysing delay (Bayraktar, 2012).

However, the challenges associated with CPM for pro-active control (Section 2.1.1) can transpose into legal settings. Case law identifies the challenges individuals with limited practical construction experience can encounter when understanding a delay analysis, but these difficulties have the potential to be addressed through BIM (Paper 1, Appendix A).

2.3 BUILDING INFORMATION MODELLING (BIM)

A literature review dedicated to BIM was published to support this research project (Paper 2, Appendix B). Therefore, this section provides a broad overview and update of BIM developments, with a focus on the link between information models and time management.

BIM is gaining international attention as a way of improving the efficiency of the construction industry but the meaning of the acronym and how these efficiencies are achieved varies between scholars and countries (McGraw Hill, 2014; NBS, 2014; Fenby-Taylor, 2016). In an attempt to provide clarity, the UK produced numerous documents to support their Government's mandate of a fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016 (Cabinet Office, 2011). This is commonly referred to as "Level 2" BIM.

"Level 2" BIM focuses on collaborative working to produce an information model, which consists of the following three components (BSI, 2013).

1. Documentation,
2. Non-Graphical Data; and,
3. Graphical Model(s).

} Information Model

BIM's approach to generating and exchanging electronic information aims to improve efficiency through collaborative working and digital construction (Infrastructure and Project Authority, 2016). The literature is unsure whether BIM has the potential to reduce claims and disputes (Dougherty, 2015) but it does identify a host of benefits associated with working in a BIM environment (Bryde, 2013). To assist with the uptake of BIM, documents have been published which overcome some of the perceived barriers against BIM adoption (Paper 2, Appendix B), such as legal and contractual issues (Paper 3, Appendix C; KCL, 2016). These documents include:

- Policy and implementation guide to align design and construction with asset use (Cabinet Office, 2012)
- Code of practice on the collaborative production of information (BSI, 2007)
- Specification for information management for the capital/delivery phase (PAS, 2013)
- Specification for information management for the operational phase (PAS, 2014)
- Standard for information exchange requirements (BSI, 2014)
- Specification for data security (PAS, 2015)
- Protocol to make best practice a contractual requirement (CIC, 2013)

Under “Level 2” BIM, each project team member is required to deliver a certain Level of Development (LoD) for each component at specified stages of the project (BIM Forum, 2015). LoD refers to the level of graphical model detail plus the level of documentation and non-graphical data. The graphical model(s) are expected to be produced using object orientated software, which is more developed than traditional CAD and uses “smart” objects which interact with each other through their individual properties and awareness of space (Eastman, 2011).

The smart objects represent physical components and can be embedded or linked with documentation or non-graphical data. This opens up the opportunity for multiple dimensions (nD) (Ding, 2014), such as linking the construction schedule to the 3D graphical model to create a fact driven construction sequence. This is commonly referred to as 4D modelling (RIBA, 2012), which is not a minimum requirement under “Level 2” working but because of the recognisable benefits and limited barriers (Kassem, 2012) its use on construction projects is rising.

This is supported by technological innovations that have been developed to support the adoption of BIM (Paper 5, Appendix E), which closely align with established project management methods and subsequently do not require the need to implement cumbersome work process changes (Hartmann, 2012).

2.4 TECHNOLOGY

Literature reviews on technology related to BIM and construction disputes are included in two of the appended papers (Paper 1, Appendix A; Paper 5, Appendix E). This section presents some of the innovations that have been developed to support the adoption of BIM, which can assist with the management and analysis of delay (Section 2.1) as well as the challenges associated with claims and disputes (Section 2.2).

2.4.1 DELAY

Bespoke tools for delay analysis are limited. Instead, the tools for analysing delay tend to use technology developed for project management purposes (Vidogah, 1998). When computer-aided critical path analysis software was developed, it was hoped that it could improve the management of time on construction projects. While the software changed the way delay is managed and how claims are submitted, delay analysts still face the challenge of retrieving information and communicating their findings.

Project information management systems have the potential to address the challenge of information retrieval. Although project information management systems existed before BIM, the processes developed to support BIM adoption should improve information storage, retrieval and exchange (Section 2.3). However, owing to the volume and variety of ever changing data on construction projects, tracking and identifying problems could still prove challenging (Lee, 2010).

Visualisations have the potential to address the challenge of communicating the findings of a delay analysis. Visualisations provide faster and better insights into complex data by amplifying and reducing cognitive functions (Keim, 2006). To create effective visualisations, it is suggested that consideration should be given to the audience, scalability of the project and the intended use (Russell, 2009). Non-spatial visualisations, such as charts, have been developed to assist change management (Lee, 2013) and time management (Chiu, 2011; Chiu, 2013). However, time management can greatly benefit from spatial visualisations, such as 4D modelling.

4D modelling (space + time) is the process of developing a graphical construction sequence by linking a 3D virtual model to time related information. Initial developments in 4D modelling sought to optimise work sequences (Warszawski, 1987), compare planned with actual performance, and overcome the challenge of presenting a wealth of information in one medium (Retik, 1990). During the early stages of 4D modelling development, extensive work was required to create 3D virtual models, especially for temporary works that were unlikely to have been included in the original 3D modelling design (Retik, 1990). This, along with the associated cost, training and integration of new software, posed a barrier against the adoption of 4D modelling (Khatib, 2007). However, the adoption of BIM on projects around the world has helped overcome some of these barriers. Around 68% of construction projects are now reported to use 3D models (NBS, 2015b) and project staff are becoming more familiar with working in digital environments, which has increased the opportunity for 4D modelling.

Commercial software is available to facilitate 4D modelling but during early releases, the software tended to focus on aesthetic visualisation (Heesom, 2004). The limited application for analytical decisions restricted the application of 4D modelling for site management, resulting in its predominant use in tendering and preconstruction (Chau, 2003). Therefore, to expand the potential of 4D modelling applications, research was undertaken in production modelling and visualisation; process modelling and analysis; and, collaboration and communication (Heesom, 2004).

These developments allowed 4D modelling to assist different project team members at different project stages. However, recording the value of 4D modelling is not always well performed (Dawood, 2009), which could have contributed to its slow uptake within the construction industry (Webb, 2004) and may explain why 4D models tend to be produced for a specific purpose, instead of throughout the lifecycle of a project (Hartmann, 2008).

Some project team members who adopted 4D modelling have reported their benefits and although reports suggest that the producers of 4D information are not always the main beneficiary (Fischer, 2003), a core benefit of 4D modelling is assisting with the engagement and communication of information between different project team members (Koo, 2000). Research suggests that 4D modelling shifts the time spent on descriptive tasks, to time spent on explanative tasks, which enhance early decision making and evaluate progress against goals (Liston, 2001). This can be further improved with interactive meeting environments, which achieve more focus on predictive tasks for pro-active management (Figure 2-6).

4D modelling achieves communication benefits by removing the need to mentally associate design information with time related information. This process can be especially confusing when understanding how changes to the project will affect the construction sequence (McKinney, 1998). The removed abstraction and improved consistency can be particularly beneficial when communicating with individuals who have limited involvement with the project (Mahalingam, 2010).

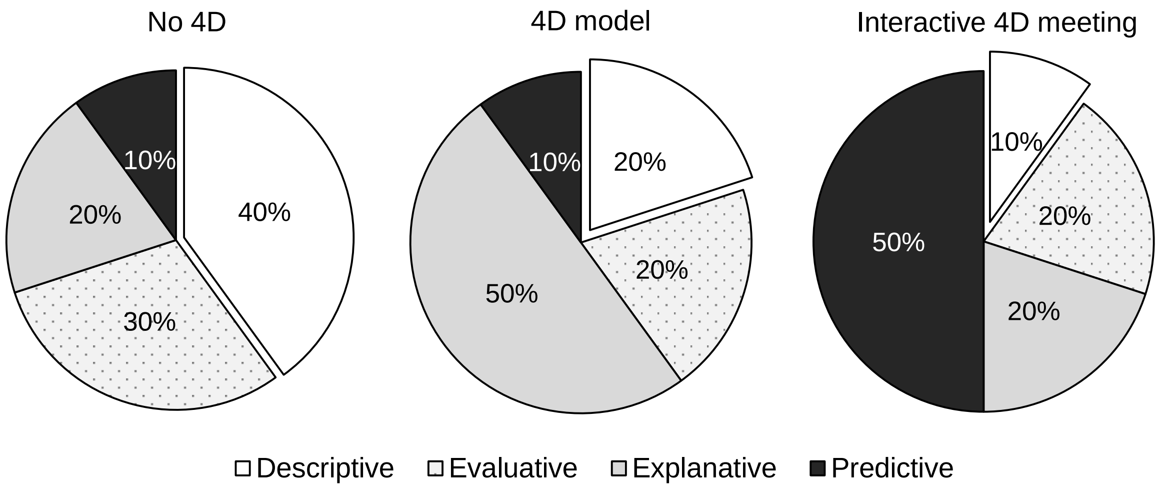

Figure 2-6: Time spent on tasks (adapted from Liston, 2001)

Advancements in 4D modelling include visualising construction progress by overlaying time-lapse photography (Golparvar-Fard, 2009) and point clouds (Han, 2015), assisting with resource scheduling (Zhou, 2015) and improving safety (Zhang, 2011). However, despite these benefits, the challenge of presenting 4D information without crowding the screen remains (Retik, 1990) and modifications to the tools and procedures are required to integrate different forms of information for project management purposes (Froese, 2010).

2.4.2 CLAIMS AND DISPUTES

Technological developments have provided tools to assist with the understanding, access and persuasive nature of evidence (O'Flaherty, 1996). Advances in hardware and software have made it possible for evidence to be displayed in legal settings (Krieger, 1992) but the uptake of this opportunity has varied between countries.

A Computer Generated Exhibit (CGE) is a form of demonstrative evidence that can be used to communicate complex information in a comprehensible format (Paper 4, Appendix D). This method of communication can provide non-experts with a better opportunity of understanding a problem (Paper 5, Appendix E) and has proven useful in assisting jurors, who can become overwhelmed by masses of information, leaving them confused, bored or frustrated with evidence (Krieger, 1992). The value of CGE's as supporting evidence expands wider than jurors and is not constrained to litigation, with the benefits extending into alternative dispute resolution (Pickavance, 2010) and claim submissions. To ensure suitability of the CGE, it is recommended that the legal culture of the audience and method of dispute resolution should be considered when creating demonstrative evidence (Ehle, 2012).

The first CGE presented in a courtroom was in 1985 (Selbak, 1994). Since then, numerous cases have used CGE's as evidence, with the United States (US) appearing to be the most familiar (Feigenson, 2009). The UK's adoption of CGE's has been restricted due to a lack of skills, distrust and deficient technology (Lederer, 1994). However, the UK's courts are going through a process of digitisation, which includes the installation of screens in the courtroom, so the uptake of CGE's are expected to rise (Paper 5, Appendix E).

When CGE's are used, they benefit from interaction, which allows key moments to be stopped and discussed before proceeding (Noond, 2002). It is suggested that care should be taken when preparing a CGE to ensure it does not present bias (Ceglinski, 2013), which could require it to be altered (*People v. Mitchell*) or result in the CGE being inadmissible as evidence (*Racz v. Merryman*). This includes manipulating or enhancing the CGE to improve clarity, such as changing the lighting or altering a camera angle. To ensure the viewer understands how the CGE can be relied upon, the standard of evidence should be explained alongside information on how the CGE was produced (Paper 5, Appendix E).

The majority of CGE's have been produced for criminal proceedings, as opposed to civil cases (Feigenson, 2009). Attempts have been made by the construction industry to use CGE's but the uptake is thought to be limited due to the perceived cost. The cost is anticipated to fall with the advent of BIM, which should provide the construction industry with greater access to object based 3D virtual models that can be coordinated with time information. Coupled with the courts increasing capability to present evidence on screen, the use of CGE's in construction disputes are likely to rise.

CGE's have been produced for disruption disputes to demonstrate a reduction in productivity (Pickavance, 2007b). This required the CGE's to focus on resource utilisation and activity durations instead of the critical path. Conversely, CGE's produced for construction delay are not widely reported. Those that have been investigated form part of this research project and did not realise their full potential, which led to recommendations on the creation of CGE's for construction delay claims (Paper 4, Appendix D).

CHAPTER 3 RESEARCH METHODOLOGY

This chapter presents the methodological considerations that underpin the research project and explains the methods adopted to address each of the research objectives.

3.1 OVERVIEW

Research is a multi-staged process that can consist of philosophies, approaches, strategies, methodological choices and procedures (Saunders, 2012a). Although each research project is different and the number of stages and sequence can vary, a generalised research process can be viewed similar to that presented in Figure 3-1.

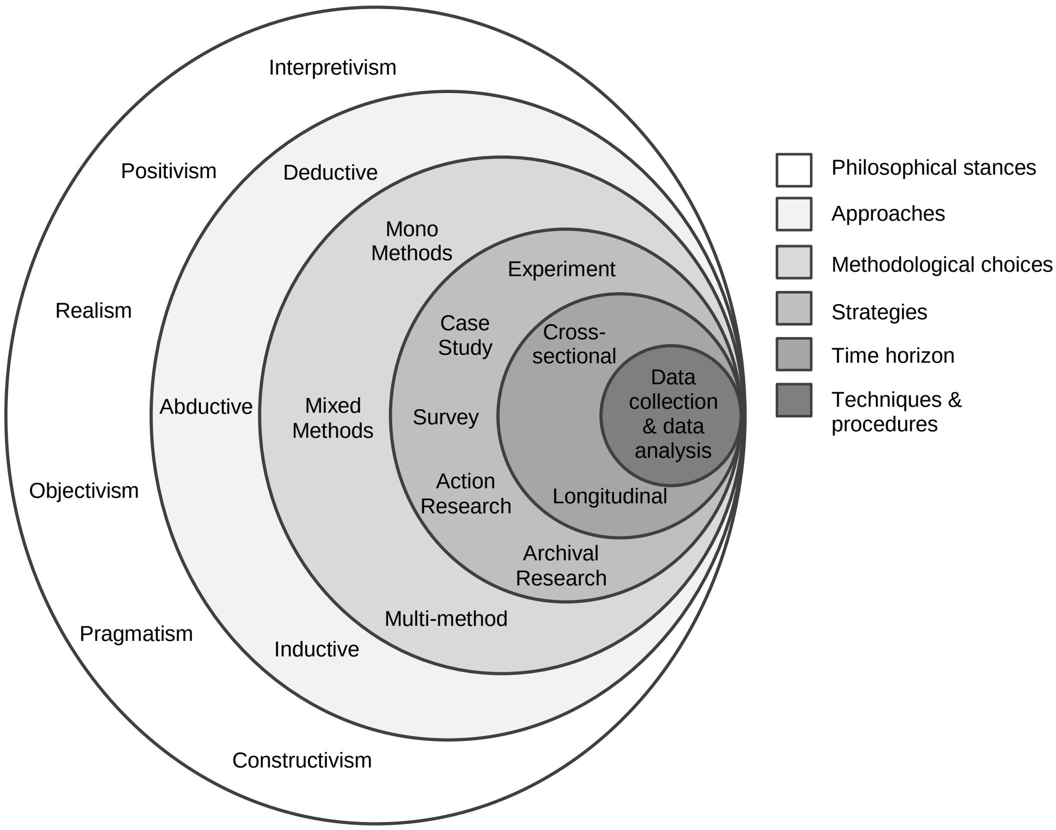

Figure 3-1: The layers of research design (Saunders, 2012a)

In Figure 3-1, the initial stages of research are demonstrated by the larger circles (philosophical stance), which contribute to the research methodology. The research methodology is the theory behind how the research was undertaken, including the logical reasoning behind decisions to solve the research problem (Kumar, 2008). As the research develops and moves through the smaller circles, it becomes more concentrated. The smallest circle (techniques and procedures) refers to the adopted research methods. The method relates to the behaviours and instruments used to select and perform research operations, and includes the techniques used to obtain and analyse the data (Kothari, 2009).

As each of the stages presented in Figure 3-1 are required to justify and explain the development of a research design (Saunders, 2012b), this chapter uses these stages as a framework to present the research methodology adopted on this research project. It is beyond the scope of this research to discuss all of the possible options for each of the research stages but acknowledgement is given to main concepts and detail is provided on the items adopted in this research project.

3.2 PHILOSPHICAL STANCE

The philosophical stance relates to how a researcher views the world (Saunders, 2012b). This influences how the research is understood and should be considered early in a project; otherwise, it can have a detrimental effect on the quality of the research outcome (Easterby-Smith, 2002). A variety of different research philosophies exist (Figure 3-1) but during this research project, the philosophy of pragmatism was adopted. No philosophy is superior to another but a pragmatic stance was appropriate to fulfil the requirements of the EngD because its purpose is to locate practical and usable solutions to a stated problem (Given, 2008). Pragmatists achieve this by using pluralistic approaches to understand a problem (Creswell, 2014) (Section 3.7).

Therefore, before a methodology was chosen, this research project began with the formation of the research problem (Section 1.4). Following this, a practical problem solving attitude was adopted which engaged the totality of philosophy (axiology, ontology and epistemology) through abductive (Section 3.3) mixed methods (Section 3.4) (Given, 2008).

3.3 APPROACH

Research approaches describe whether data is collected to test or build theory, and can be categorised as inductive, deductive or abductive (Table 3-1) (Bryman, 2012). No approach is better than another and although a combination of approaches can be used, a dominant approach usually prevails (Saunders, 2012a).

This research project allowed existing theories to be tested and developed, such as the application of BIM to improve the understanding of delay, and therefore followed an abductive approach (Blaikie, 2007). Initial research began with the problem of managing and analysing project delays, and the concept that BIM could assist through information retrieval and visualisation. This concept had not been observed in the literature but given its perceived feasibility, it was treated as a conclusion. The abductive research strategy which followed is graphically presented in Section 3.5 (Figure 3-2) and supported the iterative generation of new knowledge, through the interactions of specific to general, rather than linear deductive and inductive approaches (Blaikie, 2007).

Table 3-1: Deductive, inductive and abductive approaches (Saunders, 2012a)

	Deductive	Inductive	Abductive
Logic	When the premises are true, the conclusions must also be true.	Known premises are used to generate untested conclusions.	Known premises are used to generate testable conclusions.
Generalisability	From the general to the specific.	From the specific to the general.	From the interactions between the specific and the general.
Use of data	To evaluate propositions or hypothesis related to existing theory.	To explore a phenomenon, identify themes and patterns, and create a conceptual framework.	To explore phenomenon, identify themes and patterns, locate these in a conceptual framework and test this through subsequent data collection.
Theory	Falsification or verification.	Generation and building.	Generation or modification incorporating existing theory where appropriate, to build new theory or modify existing theory.

3.4 METHODOLOGICAL CHOICE

The research objectives can be questioned through qualitative or quantitative research. Broadly distinguishing between the two, quantitative research can be viewed as objective in nature and generates or uses numerical data, whereas qualitative research can be viewed as subjective in nature and generates or uses non-numerical data (Naoum, 2013).

The literature reports that a mixture of qualitative and quantitative approaches can be beneficial. This research design is often termed mixed methods and provides the opportunity for data triangulation; complementarity; development; initiation; and, expansion (Greene, 1989). This can be advantageous in the data collection, analysis, and interpretation stages for a single study, or across a series of studies, and helps to address some of the weaknesses associated with a mono-method design (Bryman, 2006). However, because of the various mixed method research design possibilities, the literature suggests that consideration should be given to (Leech, 2009):

- **the level of mixing**: partially mixed or fully mixed;
- **time orientation:** concurrent or sequential; and,
- **emphasis of approach**: equal status or dominant status.

Across the whole of this research project, a fully mixed sequential dominant status design was undertaken (Leech, 2009) with the purpose of development (Table 3-2). The research project fully mixed qualitative and quantitative data within the research stages in the latter phases (Objective 4 and Objective 5) to assist with informing and validating the research findings. The rationale behind this is described further in Section 3.7.4 and Section 3.7.5.

The multiple phases of data collection, analysis and interpretation undertaken for each research objective were addressed sequentially, with the findings from the previous phases informing research towards the subsequent objective. Qualitative data was dominant throughout the research project and this occurred because of the access to data that became available as the project emerged.

Table 3-2: Methodological choice for adopted techniques and procedures

Objective	Technique and procedure adopted (Section 3.7)	Methodological choice (for phase)		
		Collection	Analysis	Interpretation
1	Literature review	Qualitative	Qualitative	Qualitative
2	Content analysis	Qualitative	Qualitative	Qualitative
3	Case study	Qualitative	Qualitative	Qualitative
4	Workshop and simulation	Mixed	Mixed	Mixed
5	Questionnaire and focus group	Mixed	Mixed	Mixed

3.5 STRATEGY

The research strategy is the plan of action to achieve the research aim (Saunders, 2012a), which is to improve the understanding of delay on construction projects through BIM. This layer of the research design provides the methodological link between the philosophical stance (Section 3.2) and subsequent choice of techniques and procedures (Section 3.7) (Denzin, 2005). There are a wide range of research strategies available (Figure 3-1), each of which contain their own set of particular procedures. Therefore, to "develop" a concept, as the title of this research project suggests, the research project followed a design science research strategy.

Although design research is usually associated with an interpretist stance, if mixed methods are used (Section 3.4) it can follow a pragmatic research philosophy (Section 3.2). Design science research is found in many disciplines, but is notably used in the field of engineering to gain knowledge through the development of artefacts that aim to solve problems (Kuechler, 2011). This can be achieved through five iterative and cyclical stages (Kuechler, 2012):

- **Awareness:** Problem and potential solution are set out.
- **Suggestion:** Ways of achieving the goal are presented.
- **Development:** Suggestions are developed and implemented.
- **Evaluation:** The development (artefact) is validated to assess correctness and reasoning.
- **Reflection:** Overall conclusions noted and future work categorised.

These five stages are used as a framework to demonstrate the design science research strategy adopted on this project, which guided the research objectives (Figure 3-2).

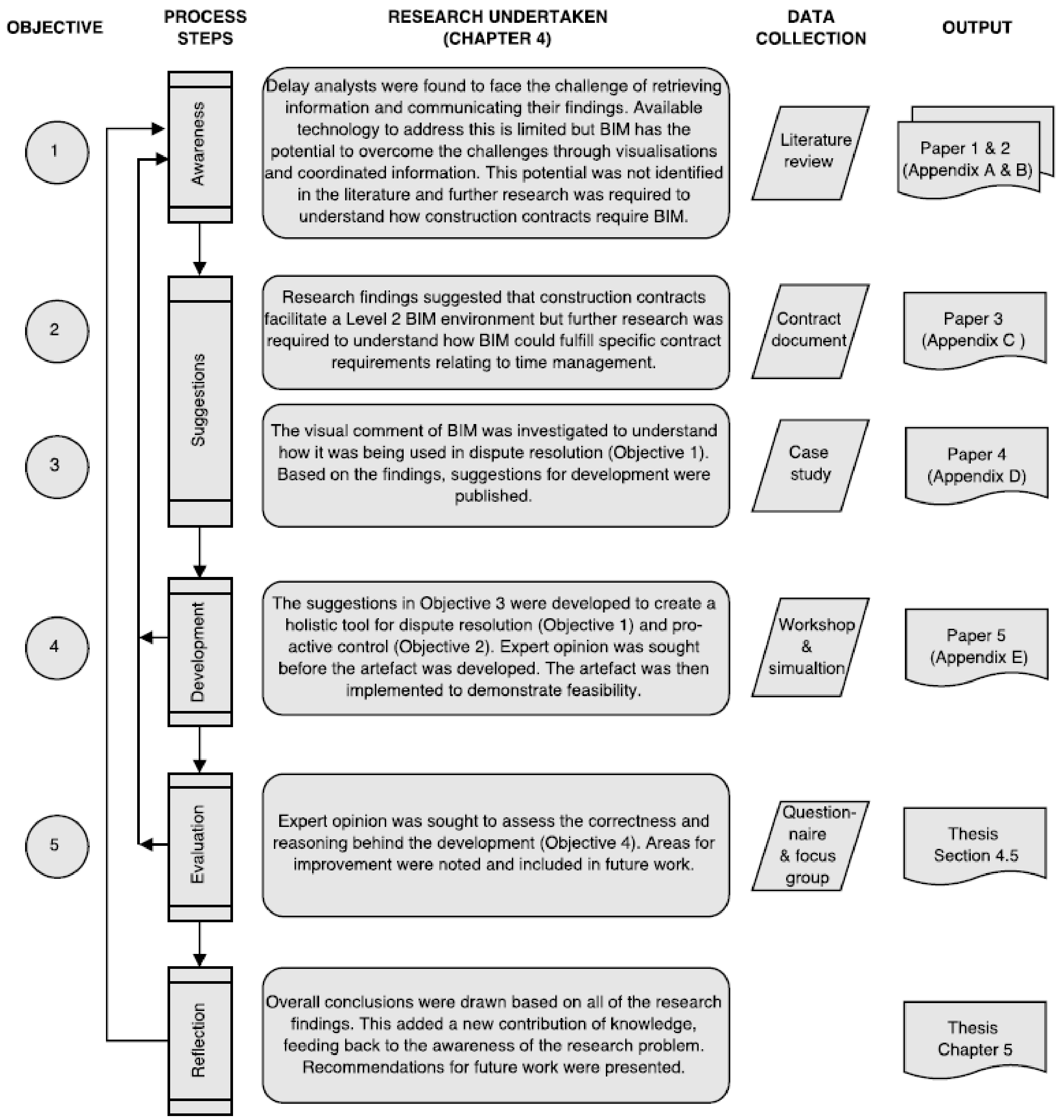

Figure 3-2: Research strategy (mapped onto Kuechler, 2012)

The process demonstrated in Figure 3-2 provides a generalised presentation of how the outputs of the published research findings served as inputs for the next research objective. However, during the research project, each objective was not constrained to a specific process step. Instead, a variety of process steps were undertaken within each objective, which later fed back into the awareness of the research problem and potential solution. Detail on the feedback loop for each objective is provided in Chapter 4.

By following this strategy (Figure 3-2), the seven guidelines for design science research were fulfilled (Henver, 2004) (Table 3-3).

Table 3-3: Design science research outputs

No.	Guideline	Description
1	Design as an artefact	An interactive Computer Generated Exhibit (CGE) was produced.
2	Problem relevance	The literature review demonstrated the challenge of managing and analysing time on construction projects and the resulting likelihood and severity of construction disputes. However, the published literature that addressed this was limited.
3	Design evaluation	During development, the artefact was validated on two separate occasions by industry experts. Furthermore, the feasibility of the artefact was demonstrated through a simulation based on case study data.
4	Research contributions	The contribution is the artefact itself. This includes the integration of modes of presentation with time management and analysis to improve the understanding of construction delays.
5	Research rigor	This chapter presents the research methodology adopted. Detail on the appropriate methods for data gathering and analysis are provided in Section 3.7.
6	Design as a search process	The iterative and cyclical nature of this research project, which searched to solve the research problem, is presented in Figure 3-2.
7	Communication of research	The research findings have been presented at conferences and published in peer reviewed journals. These publications are appended to this document.

3.6 TIME HORIZON

Given that no other research data in the field on BIM and delay had been previously published and that the research project was bound by time, a cross-sectional study was undertaken. This is in contrast to a longitudinal study, which repeatedly gathers data from the same subjects over a period of time to observe change and development (Hedeker, 2006).

3.7 TECHNIQUES AND PROCEDURES USED

Due to the pragmatic stance adopted on this project (Section 3.2), different research methods were applied to best address each of the research objectives. These were briefly summarised in Table 3-2 but additional detail on the methods of data collection, analysis and interpretation for each of the research objectives are described below.

3.7.1 OBJECTIVE 1: ANALYSING DELAY AND THE APPLICATION OF BIM

Owing to the pragmatic stance adopted on this project, the first step was to identify the research problem, which was deemed the challenge of managing and analysing delay on projects. Therefore, research towards Objective 1 sought to investigate the problem area, determine the consequence of the problem, and identify how it could be overcome through the existing literature.

Literature review

A literature review is an essential part of any academic project as it provides the foundation for advancing knowledge (Webster, 2002). Therefore, literature reviews were included as part of all the published works. In the early stages of this research project, an extensive literature review was undertaken to expose gaps in knowledge and identify areas of controversy and uncertainty; identify general patterns from multiple examples of research in the area; and, define appropriate research methodologies and methods (Robson, 2011).

The literature review addressed the goals of Objective 1 by providing an understanding of the research problem, which was the challenge of managing time and analysing delay on construction projects. The consequence of this problem was the likelihood and severity of disputes, and the potential to address the problem using technological opportunities and BIM were proposed (Section 4.1). These qualitative findings were published in Paper 1 (Appendix A) but given the advancements in BIM and technology during the research project, the findings were refined and updated for publication in Paper 2 (Appendix B). The literature review found that there was little published research that directly identified how BIM could address the challenges of managing and analysing delay. Therefore, these findings formed the basis for the research undertaken towards the next two objectives.

3.7.2 Objective 2: BIM and construction contracts

At the time of researching Objective 2, there was limited access to real life BIM contract data and publications that commented on the incorporation of BIM into construction contracts were limited. This could have been attributed to the published literature that reported that standard forms of construction contract required little change to facilitate Level 2 BIM adoption. However, industry discussion maintained that legal and contractual issues continued to restrict BIM adoption. Given the UK's mandate of Level 2 BIM, research was undertaken to understand how commonly used standard forms of construction contract in the UK were supporting a BIM environment (Paper 3, Appendix C).

An initial review of the literature identified how standard forms of construction contract were incorporating Level 2 BIM within their contractual documents. Based on these findings, the Complex Projects Contract (CPC) 2013 was chosen for further investigation as it was the first standard form of construction contract to include BIM provisions within its clauses and appendices. In addition to this, the research identified that CPC 2013 aimed to reduce the number of disputes on construction projects and that the contract placed a strong emphasis on time management. Therefore, a synergy between CPC 2013 and the topics addressed in this research project were identified (Section 1.4.2). These findings were initially presented at a Chartered Institution of Building (CIOB) conference and later explored through a content analysis.

Content Analysis

Owing to the limited publications and access to real life BIM contract data, the literature review found other publications that analysed how standard forms of construction contract overcame new key issues had used a content analysis. A content analysis is a flexible research method, which analyses text data and makes inferences from communications in relation to their use (Krippendorff, 2010). Although content analysis can be criticised for focusing attention and bias (Hsieh, 2005), the research maintained that this was an appropriate method to address Objective 2 as the application and awareness of CPC 2013 was limited because it had only recently been published. As a consequence, other forms of data collection and analysis were not possible.

The content analysis followed a directed approach (Hsieh, 2005) which used the literature findings associated with the perceived barriers of BIM adoption as a framework to analyse and discuss how they were addressed through CPC 2013's clauses and appendices. These were then broadly contrasted against other standard forms of construction contract and the future application of BIM to address contract requirements were acknowledged.

3.7.3 Objective 3: The visual capabilities of BIM to improve understanding about delay

Based on the findings of Objective 1 and some of the contractual requirements and opportunities identified in Objective 2, Objective 3 sought to investigate the visual aspect of BIM. The decision to focus on visual capabilities for communicating delay findings, as opposed to retrieving project information, was based on the availability of data.

Throughout the research project, best efforts were made to work on a live BIM project. As no BIM projects were under dispute within the sponsoring company, practical experience on a BIM project was sought from an external organisation. However, the opportunity to gather data about how organisations were managing information in a BIM environment was not possible because some firms felt they had not developed enough with their adoption of Level 2 BIM, whereas others did not want to give away their competitive advantage. Instead, data about how visualisations had been used in dispute resolution was gathered in the form of a case study. The findings were initially published at a CIB conference and later refined for journal publication.

Case study

Case studies explore complex problems in the context of their real-world environment (Yin, 2013). Although some scholars debate about how many case studies are required to support research findings, it is generally agreed that the number of case studies required will depend on the research in question (Fellows, 2008) and that a single case study, if used correctly, can be sufficient to provide a 'force of example' (Flyvbjerg, 2006).

The literature review identified that case studies had been used in other publications to demonstrate how visualisations were used as evidence in legal settings (Pickavance, 2007b; Schofield, 2011) but no published research was found specific to delay claims. Therefore, to address Objective 3, a single case study was examined.

Case study data was gathered from the sponsoring organisation about a UK delay claim. However, as is common with many disputes, the project records available were limited. The sponsoring company undertook a time impact analysis to identify the cause and effect of delay events but because of the numerous interdependent tasks, the analysis became difficult to interpret. To improve understanding, visual modes of communication were explored by the sponsoring company, who prepared a 2D simulation of their findings in Microsoft Excel. The visual approach was well received by the client, who chose to advance it into a 4D simulation using external consultants.

The research investigated the benefits, limitations and possible improvements of both the 2D and 4D models through an independent assessment. Based on the findings, recommendations for the creation of computer generate exhibits to support construction delay claims were made (Paper 4, Appendix D).

3.7.4 OBJECTIVE 4: DEVELOPING BIM TO MANAGE AND ANALYSE DELAY

This part of the research aimed to address the common causes of delay dispute by developing the recommendations presented in Objective 3 alongside other literature findings. To achieve this, training was undertaken in 3D modelling software and 4D modelling software, which had been developed to support BIM. An interactive exhibit was then developed to link modes of presentation to the 4D model and the findings were published in Paper 5 (Appendix E).

The research towards this objective was developed with consideration of the literature that reported the legal sector needed to rigorously test technology before it is used. Therefore, two stages of assessment were undertaken.

The first stage was carried out to determine the feasibility and value of using modes of presentation for delay disputes. This was achieved by collecting data in a thirty minute workshop with fifty practicing Royal Institution of Chartered Surveyors (RICS) adjudicators. The second stage demonstrated how these findings could be applied in the industry through a simulation based on case study data. The case study represented a concrete frame contractor who was required to follow a mandatory sequence of works, which were dependent on the steelwork contractor works.

Workshop

Workshops allow the researcher to engage with individuals who are concerned about a topic in order to investigate a problem and find a possible solution (Fisher, 2004). Therefore, experts in dispute resolution were sought to determine the feasibility of using modes of presentation to improve the understanding of project delay (Wieringa, 2014).

Access to this type of data is not widely available, so a workshop was chosen because it was the most suitable and effective way of gathering mixed data from the large sample of professionals. Furthermore, the approach helped generate discussion amongst the respondents, which added to the overall data collection.

The opportunity of a workshop was taken as the respondents represented 50% of the individuals registered on the RICS panel of adjudicators. Therefore, the sample size offered a good indication of the views of the population and the knowledge share provided a unique insight into construction disputes along with the opportunity to gather practical suggestions for improvement.

At designated stages in the workshop, the participants were asked to provide binary responses to structured questions asked by the presenter (Table 4-1). These responses were recorded and promoted discussion, which was captured and reported (Section 4.4).

Simulation

The workshop findings, along with other research, were integrated into a simulation. A simulation in a synthetic environment was chosen as it mitigated the risk of failure and allowed sufficient time to develop the solution. The realism of the synthetic environment was enhanced by creating as close to real life as possible by using case study data from a delay dispute on a high rise building (Zelkowitz, 1998).

The case study was chosen because it used the time impact analysis which at the time, was reported as the preferred method of delay analysis, and because some individuals involved with the dispute had found it difficult to understand the effect of delay events using the 3,500 line construction schedule.

The interactive exhibit was developed to represent a monthly window of the delay analysis and Visual, Aural, Read/Write and Kinesthetic (VARK) modes of presentation were incorporated into the interactive exhibit using numerous pieces of software (Figure 3-3). This is described in Section 4.4.

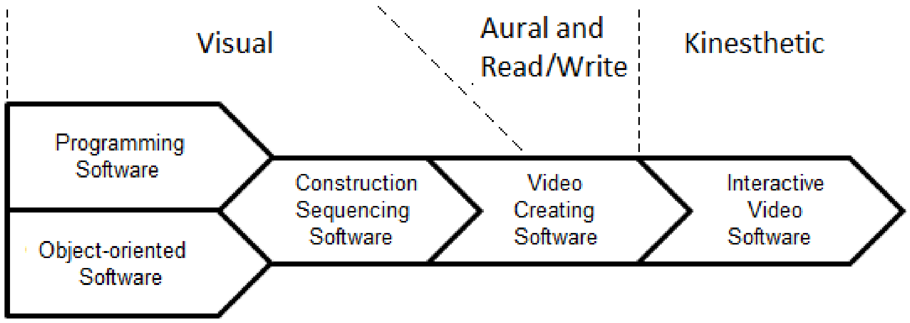

Figure 3-3: Software used to develop each mode of presentation

3.7.5 Objective 5: Validation of proposed concept

To analyse the appropriateness of the interactive exhibit proposed in Objective 4, data was gathered from a focus group and questionnaire, which were undertaken on the same day, by the same participants, who were targeted for their applicability to the study area.

4D models are a central component of the proposed interactive exhibit, so professionals experienced in 4D modelling were contacted to offer insight about the practical application of the innovation. As 4D modelling is a rising profession, the number of professionals in the UK is limited. Invitations were sent by email to 33 individuals known by the researcher asking them to participate in data collection, of which 26 took part.

The quantitative questionnaire was designed to place qualitative focus group findings into context (Brown, 2011), by understanding how the respondents were using 4D modelling in the construction industry (Section 4.5). These findings are not currently published but work is being undertaken to prepare them for publication in a project management journal.

Questionnaire

It is common for questionnaires to supplement focus group data, especially if the population is relatively small (Rowley, 2014) or if specific types of data are required (Kitzinger, 1995). Some questionnaires are undertaken away from the questionnaire designer but this can open up the possibility of misunderstanding and raises issues on the truth and validity of responses (Presser, 2004). It can also be argued that a questionnaire may not be the most suitable method to gain certain types of information, such as emotion. Therefore, it is suggested that the questionnaire should be piloted before it is disseminated to check its suitability, identify ambiguities and recognise the range of responses (Williams, 2003b). This process can also improve the usable response rate, which is usually around 25-35% (Fellows, 2008).

Acknowledging the literature suggestions, time was allocated for the participants to complete a hardcopy questionnaire before the focus group started. In an attempt to improve the rate and quality of responses from the sample, the questionnaires were provided to the respondents face-to-face, in hard copy format (Rowley, 2014) and with a pen (Sharp, 2006). Although the researcher was in the room while the respondents completed the questionnaire, the questionnaire was designed to be responded to without any assistance. To achieve this, consideration was given to each question's validity and reliability; response format; ambiguity; negative wording; jargon; and, social desirability (Fallowfield, 1995). Before the questionnaire was distributed, it was piloted to six individuals, five of which had knowledge in 4D modelling and one of which had expertise in data collection. Based on their feedback, adjustments were made to some of the question's phrasing and the response format.

The revised questionnaire was adjusted to maximise the rate and quality of responses through consideration of the questionnaire length, question order and type. The questionnaire focused on how the respondents were using 4D modelling in the construction industry and consisted of six questions that fitted onto two sides of A4, to make the task less onerous for respondents (Rowley, 2014). General questions, such as job roles, were ordered first and sensitive questions, such as standard of work, were asked later to increase response rates (Drummond, 2008). A combination of open questions and closed tick box questions were asked throughout, based on their appropriateness to achieve the objective (Vinten, 1995). These questions are presented in Section 4.5.1.

To ensure the responses were not influenced by the focus group, the questionnaires were collected before the focus group began. The questionnaire was purposefully designed to allow ease of data entry and the results were input and checked in Microsoft Excel (Boynton, 2004). As the questions were only intended to provide context for the focus group population, the findings were not cross analysed. The results were reported as a number instead of a percentage because of the small sample size (Kitzinger, 1995). To assist with understanding, the numerical data is presented in pie charts and graphs, and the text data is presented in a Word Cloud. A Word Cloud is a special visualisation tool for text, whereby the size of the word's text is influenced by its frequency. Word Clouds should not be used as a standalone research tool but they are useful as a preliminary research tool for text analysis by highlighting main topics, themes and standpoints (McNaught, 2010).

Focus group

A focus group was chosen because of its usefulness in product evaluation (Stewart, 2007). The focus group required the researcher to bring together a small number of participants, from a targeted population, to discuss the subject under "focus" through the guidance of a moderator (Morgan, 1988). This allowed the participants to share their attitudes and experiences of 4D modelling and the interactive exhibit with each other, and provided the opportunity for the discussion to be explored, commented on and clarified through group interaction (Kitzinger, 1994). Therefore, a common knowledge was identified between the participants (Hughes, 1993), as well as common needs and problems which could be addressed (Denning, 1993).

This was important for evaluating the appropriateness of the interactive exhibit, as it produced a holistic view of 4D modelling and provided the opportunity to discuss the potential application and future development of the innovation. Such a rounded response would have been difficult to achieve through individual or group interviews (Powell, 1996). However, unique issues, which may not be found in interviews, had to be considered. This included individuals dominating the group; constructing the other; tendencies towards normative discourse; and, conflicts and arguments (Smithson, 2000).

During the focus group, data was collected for 45 minutes as the 26 participants sat in a relaxed, open boardroom, so they could see each other and easily communicate. For the first 5 minutes, the participants were presented with a background to the research and were shown the interactive exhibit. Following this, the moderator went on to ask open ended questions about the interactive exhibit to subtly guide discussion and promote spontaneous interaction (Puchta, 1999).

Data was captured in the form of field notes, which recorded key points and concepts, quotations and the interaction between participants (Krueger, 2015). This did not inhibit the coordination of the group and was anonymised to avoid repercussions on the participants (Sim, 1998). The data was then analysed in relation with the questionnaire findings. Although focus group findings are often supplemented with other forms of data to enhance the quality of the analysis (Kitzinger, 1995) care was taken because qualitative and quantitative data were presented together (Wolff, 1993).

The findings of the focus group were straightforward, so a verbatim transcript was not required to perform a detailed analysis (Stewart, 2007). Instead, the field notes were used to identify the key themes that emerged through the discussion. These were categorised as:

1. Application of the innovation for:
   a. Pro-active control
   b. Claims and disputes
2. Recommendations to improve:
   a. Visual

b. Audio
c. Read/write
d. Kinesthetic

These themes were used as a framework to present the focus group's discussion (Section 4.5).

3.8 TIMELINE OF ACTIVITIES

Figure 3-4 presents an overview of when the research tasks were undertaken (Section 1.6.1). The first year of research solely focussed on addressing Objective 1 and the findings were published at a conference in September 2012, which were subsequently invited for publication in a journal (Paper 1, Appendix A). The findings of Objective 1 resulted in two parallel streams of research which complemented each other, BIM and contracts (Objective 2) and the visual capabilities of BIM to improve understanding delay (Objective 3). Research towards Objective 3 was published in May 2013, at the CIB World Building Congress in Australia. Following this publication, attention reverted to the contractual aspect of BIM, with a focus on CPC 2013. This research was invited for presentation at the CIOB contract launch event in September 2013. Upon working for Hill International in October 2013, research towards the development of BIM to manage and analyse delay started (Objective 4). This required a suitable case study to be identified and training in 3D and 4D modelling software packages. At the same time, the research towards Objective 3 was invited to be refined for journal publication (Paper 4, Appendix D). This inspired development of the research towards Objective 2, which was accepted for publication in January 2015 (Paper 3, Appendix C). Along with the simultaneous research towards Objective 4, this prompted an update of BIM and delay literature (Paper 2, Appendix B) and these findings were included in a book. While the research towards Objective 4 went through review and refinement, the findings were validated in Objective 5. Following the data collection required for validation, the thesis write up began and Objective 4 was refined for publication (Paper 5, Appendix E).

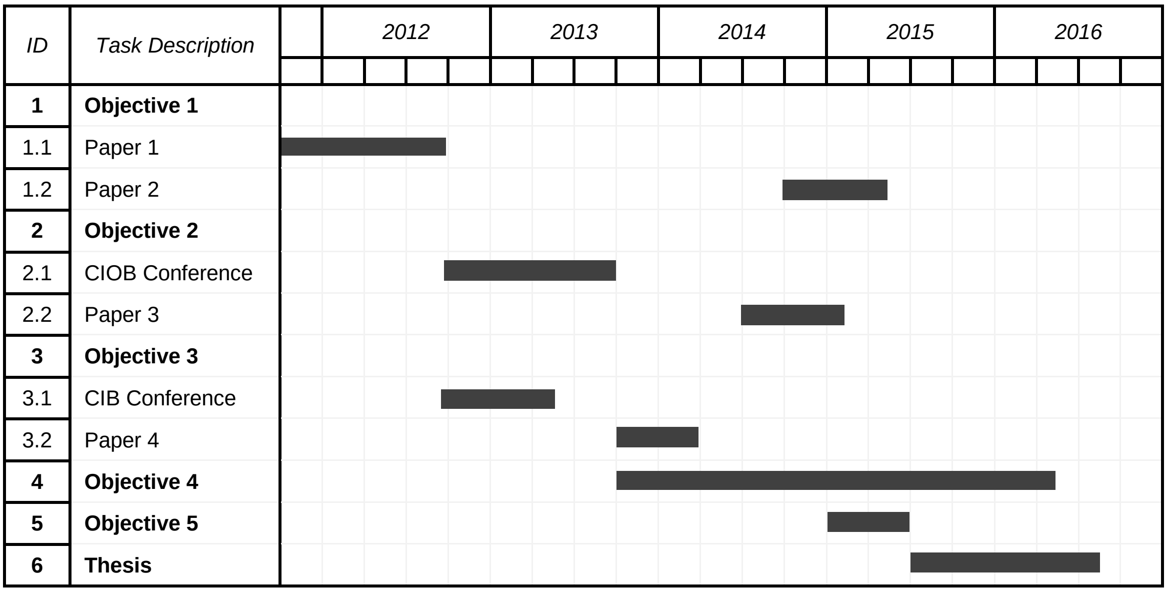

Figure 3-4: Timeline of key research activities

CHAPTER 4 RESEARCH UNDERTAKEN

This chapter presents the research undertaken to fulfil the projects overarching aim, which is to improve the understanding of delay on construction projects through BIM. This was achieved by addressing each of the research objectives using the methodology presented in Chapter 3. Within this chapter, the research objectives are used as a framework to report the research undertaken and reference is made to the published work supporting each object. These publications are appended to the document for reference and further information.

4.1 OBJECTIVE 1: ANALYSING DELAY AND THE APPLICATION OF BIM

Using textbooks, industry reports, academic papers and case law, an extensive literature review (Section 3.7.1) was initially undertaken to understand the scope of the project and expose areas of controversy and uncertainty (Paper 1, Appendix A). Owing to literature developments, especially around BIM, the literature review was continually updated and later published (Paper 2, Appendix B).

4.1.1 KEY FINDINGS

Challenges faced by delay analysts

The literature review identified the challenges faced by delay analysts (Paper 1, Appendix A; Paper 2, Appendix B). These were broadly categorised as:

- **Retrieving information:** A delay analysis should be based on fact and the choice of methodology can be influenced by the availability of records. However, delay events are not always well documented on construction projects and the information required to perform the analysis is often extracted from other forms of project record. This information is usually recorded on paper and is frequently incomplete, inaccurate and ambiguous. Although the information required to support a delay analysis might be contained somewhere within the projects records, the resources may not be available to search the masses of unstructured information that could exist.

- **Communicating findings:** Conventionally, the findings of a delay analysis are communicated using paper. Delay analyses tend to consist of Gantt charts and a report narrative, which references different types of supporting documents. On complex projects, a Gantt chart can consist of thousands of work activities and the report narrative can contain specialist terminology and information. Gantt charts can be difficult to understand, especially on complex projects, so agreeing critical activities and communicating the effect of change events can be challenging in a static environment. This is because the sum of individual changes does not always equal the overall change to the project. Furthermore, the case law identified the difficulties of communicating technical concepts and the impact of design changes, especially to individuals without practical project experience.

Technological opportunities and limitations

The research found that delay claims had not benefited from many bespoke software developments and that delay analysts often used software intended for other purposes to perform their analysis. Therefore, to investigate how the challenges faced by delay analysts could be addressed, the literature review identified the opportunities and limitations of technology being used in the construction industry (Paper 1, Appendix A; Paper 2, Appendix B).

- **Retrieving information:** The research identified that electronic document management systems were common on construction projects and that they were intended to provide a central reference point for project information. This allows the information to be accessed, sorted, filtered and reported on faster than paper or unmanaged electronic information. However, the literature noted that record keeping systems were not well performed in the construction industry. As a consequence, missing and disparate information remained on many projects.
- **Communicating the findings:** The literature review identified that evidence can be presented orally, by hand documentation or by computerised presentation of electronic data, and that visualisations were a useful way of improving the understanding of complex problems. Architectural design was recognised as the driving force behind the construction industry's use of visualisations and the associated benefits had cascaded to other project stages. Examples were found of how different sectors had used visualisations in adjudications, arbitrations and in the courtroom and suggested items to consider when used for these purposes. However, the research recognised that the value of the visual output might be questioned if it is not driven by factual information in the native file format.

The literature identified that BIM could reduce the number of delays and disputes on construction projects but it did not suggest a way to directly achieve it. Therefore, to assess this hypothesis, research was undertaken to investigate how BIM could address these technological limitations.

BIM

The literature review identified the perceived benefits of BIM and the potential to address the challenges faced by delay analysts (Paper 1, Appendix A; Paper 2, Appendix B). These were reported as:

- **Retrieving information:** The core documents supporting Level 2 adoption stated that an aim of BIM was to reduce incomplete, inaccurate and ambiguous information in the construction industry. The standards, methods and procedures to achieve this were found within these core publications and the Common Data Environment (CDE) was referenced as the way of electronically collecting, managing and disseminating information on a Level 2 BIM project. Other literature suggested that mobile devices could be used to feed information directly into the CDE to provide contemporaneous project records and some of the software was acknowledged to have the potential to link or embed project information with the 3D virtual model. Therefore, the 3D graphical model was identified to have the potential to act as a central reference point for all project information, thus providing an audit trail if required. To support this, the literature reported developments in neutral file platforms, such as Industry Foundation Classes (IFC), which allowed information to be shared between different software packages.

- **Communicating the findings:** It was well reported in the literature that BIM required the production of a 3D object orientated virtual model. Beyond this, the research identified the opportunity to create multiple dimensions (nD) by linking and embedding data and documentation with the 3D graphical model. This included 4D models, which were recognised as a way of virtually demonstrating the construction sequence and demonstrating progress at specific points in time. However, the research acknowledged that 4D modelling was predominantly used during the design and construction phases of projects.

Therefore, the potential existed to examine how 4D modelling and CDE's, which were both identified as aspects of BIM, could assist with overcoming the challenges with analysing delay. However, the perceived barriers against BIM adoption had to be considered in order to determine the feasibility of investigating the proposed solutions.

Perceived barriers against BIM adoption

Like the benefits of BIM, the reported barriers against BIM adoption were wide ranging. Therefore, the research collated potential obstacles and categorised them into the following four categories (Paper 2, Appendix B).

- **Investment:** The research acknowledged that software, hardware and training, which were not found on conventional construction projects, might be required to support a Level 2 BIM environment. Furthermore, it was recognised that the cost of this investment in these items might be higher than investing in products and services designed for conventional projects.
- **Collaboration:** Silo working and slow acceptance to change were reported as inherent problems in the construction industry that could restrict BIM adoption. The literature suggested that adversarial attitudes needed to be replaced with the sharing of power, but this could be difficult for some to accept. Additionally, the literature reported challenges with software interoperability, which was required to facilitate collaborative working.
- **Use and management of information:** The literature states that a shift from paper documentation, which is prominent on construction projects, to electronic information is required where possible. However, it was reported that electronic information is not normally well managed on construction projects and that some of the problems could be exasperated by the increased speed and quantity of information exchange, which occurs in a BIM environment. Therefore, new processes for filing and exchanging information, such as 3D virtual models, have been published. However, these may not be familiar to the workforce so the literature suggests the creation of new roles to fulfil these tasks. While this should provide greater information transparency, the literature identified that it comes with the duty to warn other project team members of potential problems.

- **Legal, contractual and insurance issues:** The literature suggested that BIM could alter the relationships between project team members and blur the lines of roles and responsibilities. As a consequence, issues surrounding liability, insurance and ownership were reported.

The research went on to investigate how these barriers could be overcome through key documents and case studies (Paper 2, Appendix B). It was found that the core documents could be made obligatory on a project, by included them within the BIM protocol, which could be incorporated within the contract through an amendment. However, research suggested that it was not common for BIM to be referenced or adopted within standard forms of construction contract, so the opportunity for these documents to address the perceived barriers might be limited.

4.1.2 NEXT STAGE OF RESEARCH

Given the opportunity to overcome some of the perceived barriers against Level 2 adoption through the core BIM documents, further research was required to understand how these documents could be made contractual requirements.

4.2 OBJECTIVE 2: BIM AND CONSTRUCTION CONTRACTS

The literature review found that BIM was not commonly referenced within construction contracts (Paper 2, Appendix B). Therefore, a content analysis (Section 3.7.2) was undertaken to understand how standard forms of construction contract were supporting a BIM environment (Paper 3, Appendix C).

4.2.1 KEY FINDINGS

Standard forms of contract

The research investigated how standardised forms of contract, which are commonly used in the UK, were attempting to facilitate a BIM environment (Paper 3, Appendix C).

- **NEC3 suite of constracts:** The research identified that a guide titled “How to use BIM with NEC3 contracts” was published, which focused on the creation of a virtual model. The publication was found to recommend how technical requirements and rights and liabilities could be inserted into the contract as well as providing advice on incorporating a BIM protocol with care into the different forms of NEC3 contract. The guide suggests that care should be taken when incorporating BIM into the contract but other than the inclusion of the protocol into the contract, the research argued that the guide offers little other guidance to assist with facilitating a BIM Level 2 environment.

- **JCT suite of constracts:** A public sector supplement was found which suggested steps and modifications to be made when design work and information exchange is governed by a BIM protocol. The supplement contained advice on incorporating a BIM protocol for most of JCT’s main contracts and sub-contracts. However, the research noted that the priority of documents might conflict if they are used in their standard form, such as inconsistent terminology.

- **PPC2000:** This contract was chosen for the UK Government's trial Level 2 BIM project because it is a multiparty contract that governs the duration of the procurement process and promotes collaboration. It was reported that the contract was used without a BIM protocol and no amendments were required for BIM on the trial projects.
- **CPC 2013:** The research acknowledged that this was the first standard form of construction contract to include BIM provisions in its clauses and appendices. However, as a relatively new standard form of construction contract, it was untested and the literature surrounding CPC 2013 was limited.

Further investigation was required to understand how specific contract clauses could assist with facilitating a BIM environment. Given the reported developments that CPC 2013 had made towards establishing a BIM environment, alongside the contract's synergy with time management and dispute avoidance aspects of the research project, further investigation was undertaken into CPC 2013.

Facilitating a BIM environment in CPC 2013

To assess how CPC2013 facilitated a BIM environment, an investigation into how the contract's clauses and appendices addressed the perceived barriers against BIM adoption was undertaken (Paper 3, Appendix C). Therefore, the barriers previously identified (Paper 2, Appendix B) were used as a framework to report the contract's developments.

- **Legal and contractual:** The content analysis found in the contract, the ownership of information is retained by the creator and licences can be granted so information can be used by other project team members. Roles and responsibilities are assigned in a matrix and the project information is kept secure by a Data Security Manager. The maintenance of the 3D virtual model is reliant on a BIM protocol, which should be specified in the contracts appendices. However, the research identified that this could produce an overreliance on the BIM protocol, which might not appropriately cover all items in its standard form. Furthermore, the research acknowledged that conflicts between terminology and the hierarchy of CPC 2013 and a BIM protocol might exist, so alterations may be required. Additional agreements were found to be needed to include other project team members, as CPC 2013 is only a two party contract between the client and the contractor.
- **Collaboration:** CPC 2013 was found to address collaboration through technology and people. The contract states that published information should be exchanged using native files to provide the opportunity for its interrogation. However, it was recognised that relevant software would be required to access information in its native format, which might not be available to the receiving party. In addition, specifications for software requirements were found in the contract but they only related to the working schedule and progress records. Therefore, the research recognised that this did not directly address interoperability issues associated with 3D virtual models. Furthermore, it was acknowledged that CPC 2013 focused on BIM as a virtual model, not as a collaborative process of working. Nonetheless, the research found that collaboration

was emphasised throughout CPC 2013's contract provisions, with overarching clauses requiring project team members to co-operate in a spirit of mutual trust and fairness. This was found to be complemented by collective goals and openness on risk management, but it was suggested that the prescriptive contract provisions required to achieve this could hinder collaboration and might not be enough to change the adversarial attitude of the construction industry. Therefore, CPC 2013 acknowledged the possibility of contentious issues and a procedure was established in an attempt to reduce the frequency and severity of disputes. However, this approach suggested that collaboration might be expected to fail.

- **Use and management of information:** The research noted that CPC 2013 was released before key documents supporting Level 2 BIM adoption were published. As a consequence, the contract does not make direct reference to the available guidance. However, the research identified that these documents could be incorporated into the contract through a BIM protocol, which is required to be stated in CPC 2013's appendices. The contract was found to promote the use of electronic information, which is to be exchanged in a CDE, but the research identified that this is not compulsory. Other methods of information exchange are recognised and allowed in the contract but it was acknowledged that these methods might not be appropriate for managing the mass of data found in a BIM environment. The research indicated that CPC 2013 assigns roles and responsibilities for producing information in a matrix, which is reliant on the project stages being well established and understood. Uniclass is used to categorise design elements, which the research noted may not be the most appropriate classification method for BIM projects, and that the information produced is to only be used for the project stage it was assigned. Early warnings were acknowledged as a way of communicating potential risks to other project team members and if the 3D virtual model could not sufficiently produce information, CPC 2013 allowed the use of additional software.
- **Investment:** The contract does not explicitly state who should bear the cost of software, hardware and training but it does consider that the investment will have value for the purchasing organisation beyond the project. Therefore, the contract suggests that the cost should be included in the general overheads.

The specific contract clauses for all of these findings are referenced in the appended document (Paper 3, Appendix C) and a broad comparison with the other standard forms of UK construction contract was undertaken.

Comparison with other standard forms of contract

Based on the findings of the literature review and content analysis, the BIM developments of CPC 2013 were contrasted with NEC3, JCT and PPC2000 (Paper 3, Appendix C). Overall, CPC 2013 was found to be more prescriptive than the other standard forms of contract but in relation to BIM, the reoccurring themes between the different standard forms of construction contract are summarised as:

- **BIM protocol**: NEC3, JCT and CPC 2013 were all found to require a BIM protocol. The research recognised that a BIM protocol is a mandatory requirement in CPC 2013 if a Level 2 BIM project is undertaken and reference to the BIM protocol is made in the contract. However, NEC3 and JCT require steps for the protocol to be included. Conversely, the literature suggested that PPC 2000 did not utilise a BIM protocol on a Level 2 trial project.
- **Amendments**: CPC 2013 was found to be the only standard form of construction contract to include BIM provisions in its core clauses and appendices. The research identified that amendments and special conditions may be required for CPC 2013 to facilitate a Level 2 environment but these amendments are unlikely to be as rigorous as those required for NEC3 and JCT. However, it was suggested in the literature that PPC 2000 was adopted on a Level 2 BIM project without the need for any amendments.
- **Beyond Level 2:** The research concludes that all standard forms of construction contract and guidance that has been published to support BIM adoption needs to be reconsidered if projects go beyond Level 2 BIM.

4.2.2 NEXT STAGE OF RESEARCH

The research identified that there would be value in undertaking a similar research approach for each of the other standard forms of construction contract. It was also recognised that future work should be undertaken to determine the specific amendments and additions required to make each of the standard forms of contract Level 2 compatible, as well as to determine the relationships that each these contracts have with the core BIM documents.

It was acknowledged that there would be value in analysing a live BIM environment under CPC 2013. In particular, it would be interesting to understand how the technology developed to support Level 2 BIM, such as the visual capabilities, could be used to support contractual requirements for managing time and analysing delay.

4.3 OBJECTIVE 3: THE VISUAL CAPABILITIES OF BIM TO IMPROVE UNDERSTANDING ABOUT DELAY

A case study was chosen to gather data about how the visual capabilities of BIM were used in dispute resolution (Section 3.7.3). The dispute utilised the visual capabilities of BIM to assist with explaining critical interdependencies between activities that led to delay. A 2D and a 4D simulation were produced to help improve understanding of these interdependencies and the benefits, limitations and potential opportunities of the simulations were investigated as part of the case study (Paper 4, Appendix D).

4.3.1 KEY FINDINGS

Computer Generated Exhibits

The literature reported (Paper 4, Appendix D) that the entertainment industry had driven developments in Computer Generated Imagery (CGI) and that different forms of CGI included:

- Visualisations: Representation of information at a point in time;
- Simulations: Advancing visualisations through time; or,
- Animations: A simulation that the user can interact with.

Case law demonstrated how some of these CGI's had been used as Computer Generated Exhibits (CGE) to provide a form of demonstrative evidence in legal settings. The literature suggests that CGE's were advantageous in these situations as they assisted with understanding and classifying facts for the judge a jury. The literature reported how CGE's had been used to demonstrate construction sequences and that CGE's could be classified in increasing probative value as:

1. Descriptive: Not factually driven but a "story" based on facts;
2. Introductory: Summary of principal issues but can omit parts;
3. Illustrative: Description of something which could not normally be seen; or,
4. Evidential: A different way of demonstrating primary evidence.

Therefore, investigation was undertaken to understand how CGE's had been used in construction delay claims (Paper 4, Appendix D).

Case study

The research utilised a delay analysis that was undertaken to investigate the design and construction of a reinforced concrete frame, staircases and provisions for tower cranes. The time impact analysis identified temporary works restrictions as prominent delaying events but the numerous concurrent tasks made it difficult to demonstrate the cause and effect of delay. Therefore, CGE was explored as a way enhancing understanding.

2D simulation

A simulation for an area of the project was created in 2D using Microsoft Excel. The simulation compared as-planned versus as-built progress side by side, with each floor broken down into five different activities and colour coded (Figure 4-1). The progress of the works was automated by linking the visualisation to a bespoke Microsoft Excel construction schedule.

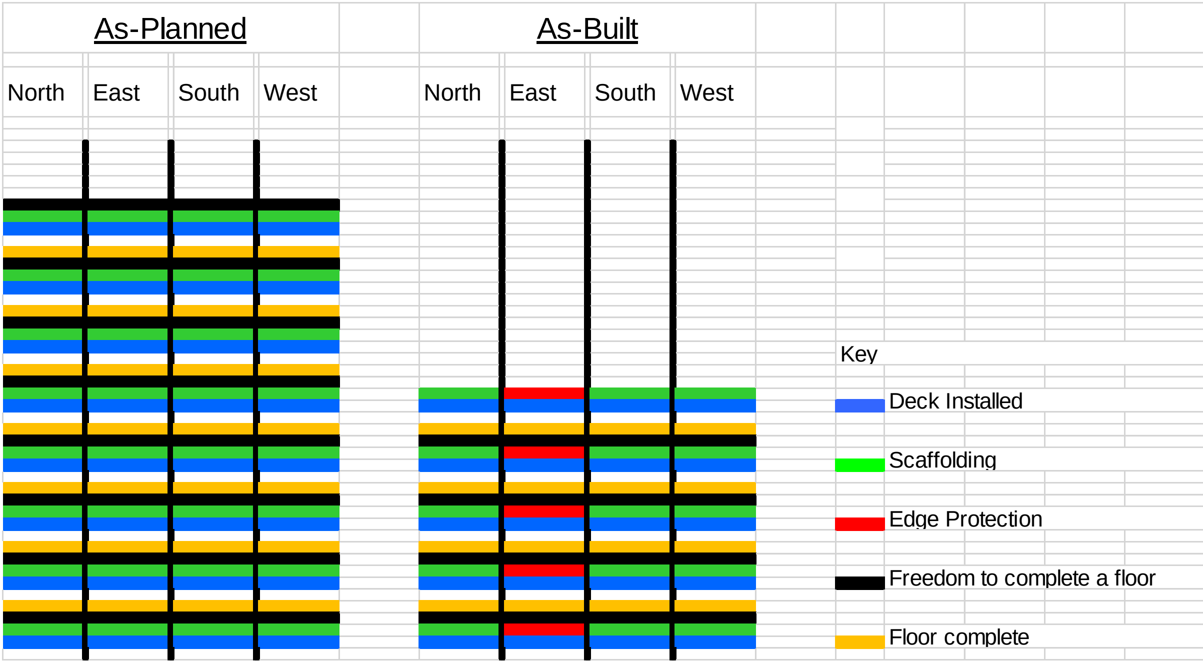

Figure 4-1: Static view of progress from 2D simulation[7]

Benefits of the 2D simulation included:

- clear understanding of the item in delay and the effect on the project;
- a side by side comparison of planned and actual progress; and,
- the ability to pause or select specific dates to compare progress at a point in time.

Limitations of the 2D simulation included:

- limiting the number of work activities and not displaying resources ;
- not linking with construction scheduling software;
- not including scheduling logic;
- static views, not to scale, not realistic or visually appealing, which could give misconceive and did not assist individuals who had not visited the site; and,
- only showing one building, not the whole project.

[7] This static view of the 2D simulation shows issues with the East elevation, where edge protection is installed but scaffolding has not commenced. At the specified date, the overall as-built progress is three levels behind what was planned.

Possible improvements of the 2D simulation included:

- harnessing the software's interoperability and including annotations and links to documents for additional information; and,
- making it more visually appealing.

Some of the limitations could have been resolved if the simulation had been continually developed; however, it was stopped and a 4D simulation was progressed instead.

4D simulation

The 4D simulation incorporated all of the contractor's work and colour coded each of the superstructure levels (Figure 4-2). The 3D model was linked to an as-planned schedule and delayed items were highlighted in red, returning to their item colour once complete. The software was saved in an open file format, so it could be viewed without the native 4D software, but alterations to the model could not be made. The 4D simulation was not progressed beyond the first revision.

Figure 4-2: Static view of progress from 4D simulation[8]

Benefits of the 4D simulation included:

- realistic virtual representation of the works, which could assist with understanding the site without ever visiting;
- the ability to pan around the virtual model and investigate progress from different viewpoints; and,
- a fact driven simulation, meaning the full details of the construction schedule did not need to be understood to understand the construction sequence.

[8] This static view of the 4D simulation shows a completed structural frame of a building on the project.

Limitations of the 4D simulation included:

- not demonstrating the cause and effect of delay events;
- colouring delay items red on the as-planned model, which made delay unclear as the works appeared to progress to plan;
- not distinguishing between delay to progress or completion;
- not demonstrating the interdependencies between works or emphasising stop-start relationships;
- it's lack of impact;
- no linking the simulation with supporting evidence; and,
- not modelling temporary works and resources that contributed to delay.

Possible improvements of the 4D simulation included:

- improving the communication between the 4D modellers and the delay analysts;
- demonstrating as-planned versus as-built models side by side;
- providing multiple viewpoints to represent delay around the site at specific moments in time; and,
- incorporating or linking evidence to the 4D model.

Recommendations for improvement

Based on the benefits and limitations of the 2D and 4D models, the research recommended general improvements when using CGE's to support construction delay claims (Paper 4, Appendix D). These were summarised as:

- **Cost benefit analysis:** The research identified the need to determine what value the CGE would add to the claim and for it to be developed accordingly. Specific attention should be given to LoD and the available budget, which should take into account the need for review cycles. It was recognised that the greatest value of a CGE would be early in the claims process and a lower LoD and probative value might only be required at this stage. This approach was identified as a way of reducing the likelihood of the claim developing into a dispute. It was noted that CGE should become cheaper and easier as access to virtual models increased alongside the growth of BIM.
- **Determine what is necessary:** The research split this into two sections. Firstly, the research noted the need to identify the required software and expertise, as in-house skills may be appropriate to produce a sufficient CGE. Secondly, the research found that simple CGE's can be effective. The research advised creators of CGE's to carefully consider balancing viewer engagement against the clarity of the message. The research suggested the need to consider the use of colours and to only include information relevant to the claim. This was recognised as a way of avoiding distraction and emphasising critical items, without patronising the viewer. The research recommended that CGE's did not exceed 20minutes and 'energy shifts', such as oral

discussion, could be used to break up the CGE and improve attention. The need to identify the intended use of the CGE, to ensure the LoD was appropriate, was also acknowledged.

- **Side by side comparison of as-planned versus as-built with timeline:** The research identified that a direct visual comparison of as-planned and as-built progress could improve understanding about the effect of delay events. It was also noted that a readable timeline should be present in the CGE to allow the progress of the project to be understood at points in time.
- **Communication:** The research recognised that some of the limitations could have been eradicated if there was communication between the delay analyst and the CGE's creator. The research stated that it was unfair for both disciplines to understand the complexities of each other's work and that if CGE's were to become commonplace, an individual with an appreciation of both disciplines could sit between the two to assist with development. Collaborative workshops between the two parties, where the CGE is developed along with continual review cycles, instead of isolated development, could also improve the standard of the CGE and help unlock project knowledge.

4.3.2 NEXT STAGE OF RESEARCH

The logical next step for research was to test the proposed recommendations. This is intended to add knowledge and raise awareness about the use of CGE's on construction disputes, something that was not found in the literature.

4.4 OBJECTIVE 4: DEVELOPING BIM TO MANAGE AND ANALYSE DELAY

Following a literature review which identified the legal sectors need to rigorously test technology before it is used in practice, a workshop and simulation (Section 3.7.4) were undertaken to develop BIM to manage and analyse delay (Paper 5, Appendix E).

4.4.1 KEY RESULTS FINDINGS

Literature review

Use of technology in the legal sector

The literature review (Paper 5, Appendix E) identified that investment in technology by law firms remained lower than other industries but the recession had prompted the legal sector to increase their use of Information Technology (IT). The literature attributed part of this slow adoption to the legal sectors need to rigorously test new technology to ensure it is being utilised correctly and is fit for purpose. Therefore, it was acknowledged that any research and development that addressed delay disputes would require multiple stages of assessment.

The literature review went on to investigate how the courts were using technology and it was found that the UK criminal justice system was replacing paper based working with digital technology to help improve efficiency. This included the installation of screens in courtrooms to allow advocates to provide digital evidence straight into court using their laptop or handheld device.

With these advances in mind, the literature review went on to investigate the potential to address the common causes of delay dispute.

4D modelling

4D modelling was found to be particularly useful in communicating information to individuals with a lack of site related knowledge, as they no longer had to imagine and interpret the design and construction sequence in their mind. The research recognised that this could directly address some of the challenges faced by delay analysts and coincided with research that suggested that visual information was preferred over oral information, as it improved understanding and retention (Paper 1, Appendix A). This led the research to investigate how information could be communicated more effectively.

Modes of presentation

To understand the science behind communicating information, research was undertaken into the psychology of learning. The literature identified that an individual's ability to understand information can be influenced by the sensory mode of presentation, which can be categorised as:

- Visual: Graphical and symbolic information
- Aural: Heard information
- Read/Write: Printed words
- Kinesthetic: Learn through application and multi-sensory experiences

These perceptual modalities are often termed VARK modes of presentation. The literature states that individuals have different sensory preferences and that learning styles are not specific to a job type. For example, the literature reported that lawyers have a diverse set of sensory preferences. Furthermore, research in this field recognised the benefits of combining different modes of presentation but suggested that care must be taken to not overload the recipient with information.

Interactive videos

Subsequently, an investigation was undertaken to identify a way of incorporating VARK modes of presentation into a single medium, without distracting the viewer. The research identified the possibility of using interactive videos to achieve this, as they allow the viewer to interact with different modes of presentation by clicking on tags that track assigned items in the video. This solution was chosen for development as it allowed individuals to use their sensory preference without the need to foreknow their preferred learning style.

Workshop

A workshop with dispute resolution experts was undertaken to gather data about CGE's (Section 3.7.4). The questions asked during the workshop and the results are summarised in Table 4-1.

Table 4-1: Summary of workshop results

Question no.	Description	Yes response	
		Number	Percentage
1	Have you ever been provided with a CGE to support a construction claim?	16	32%
1a	Was the CGE useful in assisting your judgement?	7	44%
1b	Was the CGE not useful in assisting your judgement?	9	56%
2	Would you find CGE, like that demonstrated, useful in assisting your understanding of a construction claim?	22	44%
3	Do you feel there would be value in adding Aural and Read/Write functions to CGE's like that demonstrated?	47	94%

During the workshop, the following suggestions were discussed.

- A CGE should only display fact and the information driving the CGE should be made visible to the viewer.
- Interrogation of a CGE would be preferred, but it is not fundamental.
- A minority stated that there will always be an element of doubt that the CGE is accurately reflecting the facts if it is unable to be interrogated.
- The creator must state how the viewer can rely on the CGE.
- In its most basic form, a CGE could be used to give an overall impression of what occurred on the project.
- CGE's could be useful in situations where there is only a short duration to understand the dispute, such as adjudications.[9]
- It would be useful for the viewer to see actual and planned progress, along with links or signposts to supporting evidence.
- A CGE should be kept as simple as possible, with sufficient explanation to communicate what's occurring on screen.
- A similar approach could be useful for the pro-active management of a project.

The findings demonstrated that CGE's are not widely used to support construction claims and when they have been used, they have not always been helpful, which was pertinent with previous research (Paper 4, Appendix D). The workshop participants appeared unaware of the different values of CGE

[9] However, the correct project information and analysis needs to be performed in advance, or the CGE needs to be able to be created quickly, to meet stringent timeframes.

and a correlation between demographic of the sample size and suspicion about technology accuracy may exist. However, the majority of the workshop indicated that there would be value in integrating VARK modes of presentation into a CGE, so further research was undertaken to develop this concept.

Simulation

Many of the points raised by the workshop participants overlapped with previous research recommendations (Paper 4, Appendix D), which provided confidence in the research findings. Therefore, a simulation of an interactive exhibit was developed (Figure 4-3) to demonstrate how the findings could be incorporated into practice (Table 4-2). Larger images of the simulation are included in Paper 5 (Appendix E).

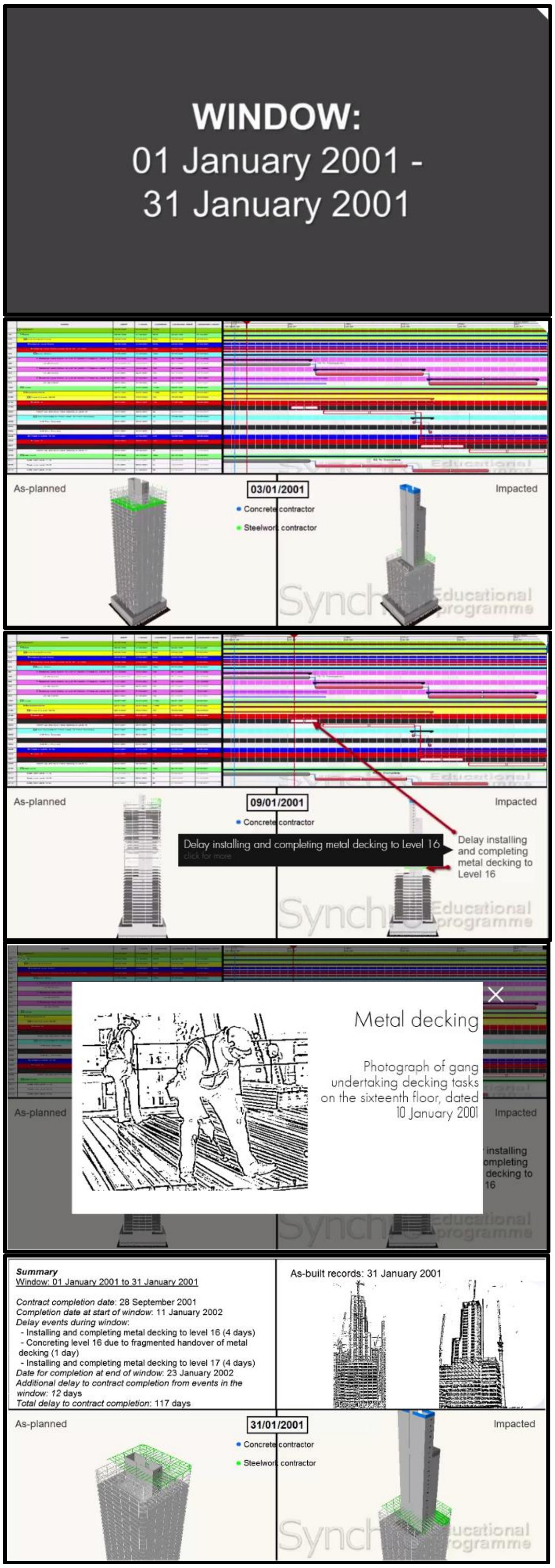

Figure 4-3: Static view of interactive exhibit

Time	Description
00:01	Aural description explains how the interactive exhibit can be used and provides background information to the delay claim. Aural description of what is occuring on screen is provided throughout the exhibit.
00:50	A side by side visual analysis of as-planned and as-built progress are presented. As the timeline progresses through the delay analysis, the camera angle pans both virtual models. Activities performed by each trade are colour coded. Concrete contractor (blue) and steelwork contractor works (green).
01:06	Delay events are marked on the Gantt chart in black. For the duration of the delay event, black text boxes appear on screen to provide a description about the delay. These text boxes act as the clickable tags.
01:06	When the tag is clicked, the exhibit is paused and a box containing additional information such as pictures, videos or text references to the report narrative. If the tag is not clicked, the exhibit progresses as normal.
2:39	At the end of the exhibit a summary is provided to show the effects of delay during the window. As-built records are included to allow comparison with the as-built 3D virtual model. The interactive exhibit of the next window could be accessed by clicking the green arrow.

Table 4-2: Incorporating recommendations into the interactive exhibit

No.	Recommendation	Description
1	Cost benefit analysis	An evidential CGE was deemed most appropriate for the multimillion pound claim.
2	Clearest form	Only steel and concrete works were displayed in the 3D model. They were colour coded and uninfluential resources were not included to avoid distraction. All four modes of presentation were used to assist with demonstrating the delay in its clearest form. • *Visual*: Fact driven as-planned and as-built 3D models [see No.3]. • *Aural*: Summarised report narrative was played to describe what was occurring on screen. • *Read/Write*: Text boxes provided detail about delays as they occurred and acted as clickable tags, which could be used to access further text and cross referenced other evidence, when activated. • *Kinesthetic*: Clickable tags provided the opportunity for the viewer to interact with the exhibit.
3	Side by side comparison with timeline	The delay analysis was displayed and used as-planned (baseline) progress against the as-built (time impacted) in a single Gantt chart. The delay analysis drove the as-planned and as-built 3D virtual models, which were placed side by side to allow for direct comparison.
4	Communication	There was communication between the 4D modeller and the delay analyst, with a final check to ensure the output was correct.

Whilst the recommendations were being incorporated into the interactive exhibit, challenges that related to some of the difficulties associated with implementing technology were encountered. This included:

- **People**: Balancing the different modes of presentation evenly to suit a diverse set of learning styles. Visual was identified as the primary mode of presentation in the interactive exhibit and the value of the modes of presentation need to be assessed;
- **Process**: Simultaneously producing consistent detail between the 3D virtual model and the construction schedule. The research noted that multiple review cycles were undertaken retrospectively, even when only one individual was creating both sets of data. Therefore, it was predicted that it would be more challenging across multiple individuals and project teams, in an active project environment; and,
- **Technology**: Interoperability of software, especially importing old construction scheduling data into the construction sequencing software. This resulted in the data being distorted, which needed to be fixed and checked. Further technology challenges existed with data storage, with concerns over the data being held on an external server.

Having integrated the recommendations into the interactive exhibit, the benefits and limitations for each mode of presentation in the interactive exhibit were identified (Table 4-3).

Table 4-3: Benefits and limitations of each mode of presentation in the interactive exhibit

Mode of presentation	Summary	Benefits	Limitations
Visual	Animation of delay analysis showing the side-by-side analysis of as-planned (baseline) progress and the as-built (time impacted).	Demonstrates the complex interdependency between trades. Side-by-side analysis shows change events and the effect on the project.	If 3D and 4D models do not exist, creating them can be resource intense. Issues with interoperability of software packages.
Aural	Aural explanation of what is occurring on screen. Likely to be a summary of the written report narrative.	Can be turned on/off at viewer's discretion.	Detail might not be sufficient as a standalone item.
Read/Write	Text captions summarise key events and pieces of information.	Summarises and draws attention to key items.	Cannot be turned on/off when interactive exhibit is created. Detail might not be sufficient as a standalone item.
Kinesthetic	Novel way for the viewer to interact with the simulation and gain additional information using clickable "tags".	Simple and effective way to interact with the exhibit to gain additional information. Can be played on a handheld device to enhance Kinesthetic learning.	All senses cannot interact with digital technology for full Kinesthetic learning. Interaction is limited, viewer cannot navigate the model. Data held on a server external to those involved with the project.

4.4.2 NEXT STAGE OF RESEARCH

Following these findings, the research identified the need to investigate the value for each individual mode of presentation in the interactive exhibit to ensure it equally benefits all learning types. Additional research into software interoperability, especially for 4D modelling, was not found in the literature so further research into this area was identified as valuable. Furthermore, the research recognised the need for additional stages of assessment before the proposed interactive exhibit should be used in practice.

4.5 OBJECTIVE 5: VALIDATION OF PROPOSED CONCEPT

To validate the appropriateness of the interactive exhibit for pro-active time management and retrospective analysis of delay (Section 4.4), a questionnaire and focus group was held with 4D modelling experts (Section 3.7.5).

4.5.1 KEY FINDINGS

Questionnaire

Questionnaires were completed by 17 of the 26 participants, who all had active involvement in 4D modelling. The majority (15) of the respondents held different job titles, with the exception of 2 BIM Managers, and the keywords from each job title are presented in the Word Cloud below (Figure 4-4).

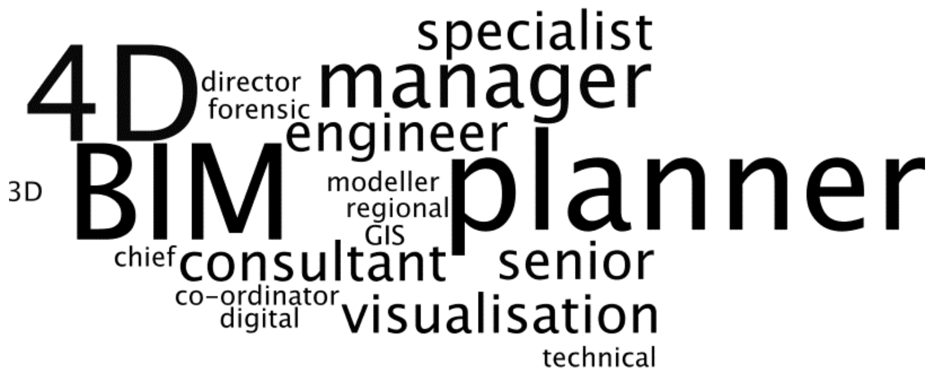

Figure 4-4: Word Cloud of focus group's job titles

Figure 4-4 demonstrates the diversity of job titles attributed to the respondents involved with 4D modelling, some of whom (5) have a specific 4D title and others (12) who perform 4D modelling tasks under the rubric of traditional job titles. The term, “BIM” appeared 5 times, sometimes (2) combined with the term “4D”. However, the term “planner”, which also featured 5 times, was not interchanged with either “BIM” or “4D”. Although a small sample size, the Word Cloud demonstrates the diverse job titles currently involved with 4D modelling tasks and the seniority of the respondents.

The respondents experience of 4D modelling varied between producers (10), navigators (4) or a combination of both (3) (Figure 4-5). In the last three years, 13 of these respondents had worked on less than 8 projects that used 4D modelling (Figure 4-6). The remaining respondents (4) had worked on over 30 projects that utilised 4D modelling, one (1) of which had produced 130 low LoD 4D models for tendering purposes.

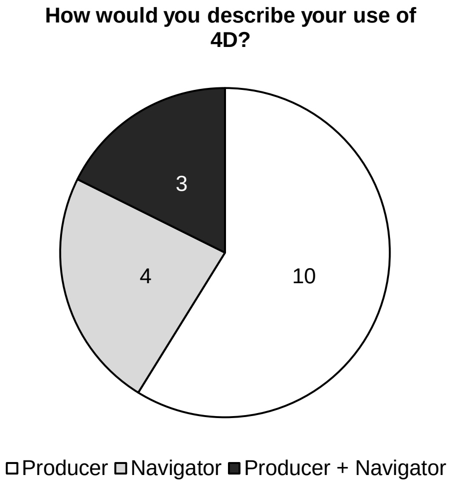

Figure 4-5: Respondents use of 4D modelling

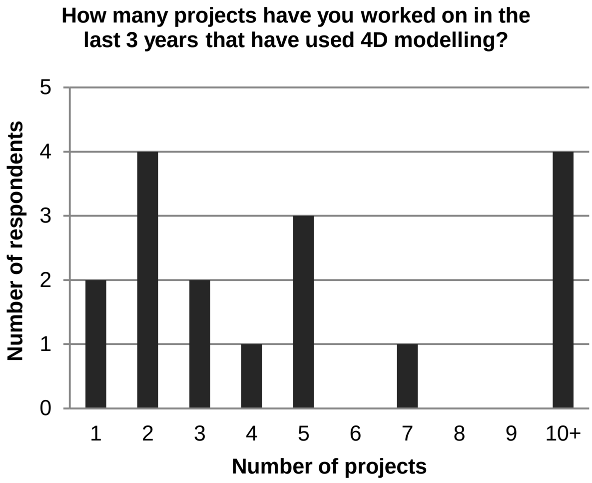

Figure 4-6: Number of projects using 4D modelling

The research identified that five (5) of the respondents had used 4D modelling on all of the projects they had worked on in the last 3 years (Figure 4-7) and collectively, the respondents indicated that 4D modelling was being utilised by the construction industry at each project stage (Figure 4-8). However, none (0) of the individual respondents had used 4D modelling at each project stage and only one (1) respondent had used 4D modelling during the handover and closeout stage of a project. Therefore, it is unclear whether projects are using 4D models throughout their lifecycle.

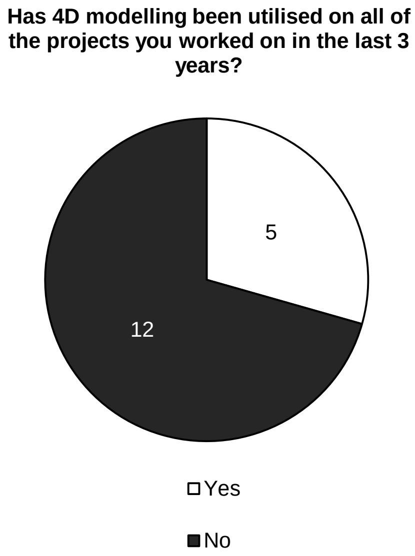

Figure 4-7: Use of 4D modelling on all projects

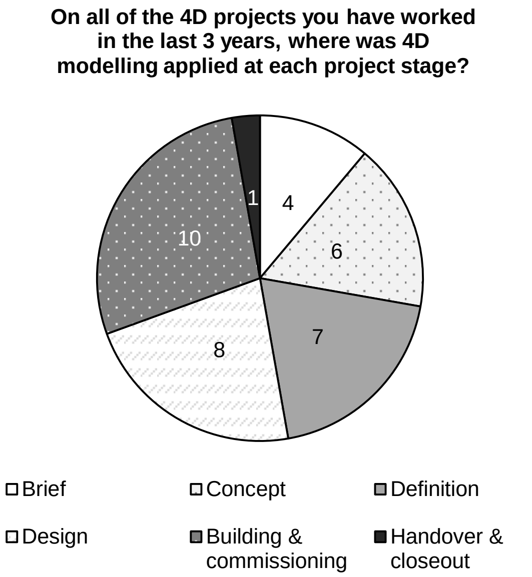

Figure 4-8: Use of 4D modelling at different project stages

Overall, the respondents indicated a split in the standard of models they were producing (Figure 4-9), but it is unclear from the questionnaire whether the LoD in the 4D models was dependent on the project requirements or the skills of the workforce. Furthermore, it is unclear on how useful the different standards of 4D modelling were on the project.

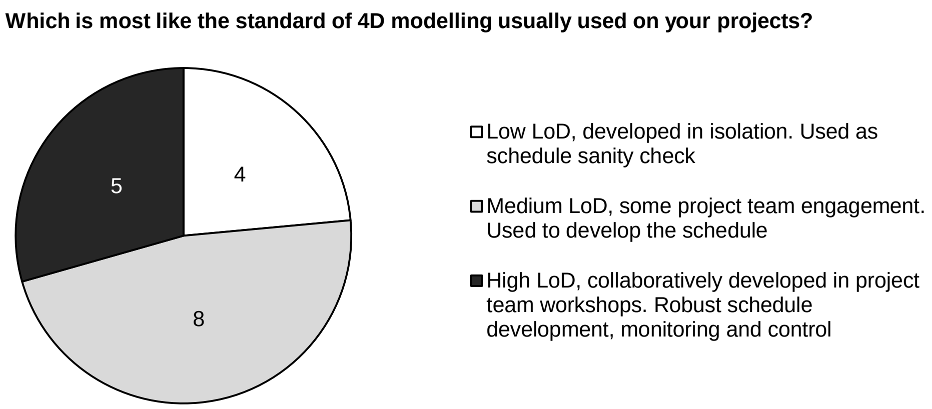

Figure 4-9: Standard of 4D models

The respondents who held the term “4D” within their job titles (5) were the same individuals who had only worked on only 4D modelling projects in the last 3 years and produced the highest standard of 4D models. Therefore, it can be inferred that 4D modelling was the primary job role for these respondents. Conversely, it can be inferred that the other respondents (12) undertook 4D modelling along with other day-to-day tasks, which in turn reduced the standard of 4D modelling.

Focus group

Although the focus group recognised the value of integrating VARK modes of presentation with time management, the focus group agreed that the proposed interactive 4D exhibit was not suitable for pro-active time management purposes in its current form. The participants of the focus group identified that pro-active time management needs to be a fast and open process, which was limited by the video.

However, all of the focus group agreed that the interactive exhibit could be used for retrospective analysis, with some participants identifying the value of the proposed concept for tender purposes and knowledge sharing and management. The participants highlighted that the video focused on the Visual mode of presentation and that the information presented in the interactive 4D exhibit stayed in their memory.

One of the participants explained that they had used 4D modelling to support a construction claim and urged the focus group to do the same. This participant identified the potential value of using the interactive 4D exhibit but indicated that it would need to be used in an appropriate situation, where there is the time and resources to produce the delay analysis, 4D model and interactive exhibit. Furthermore, the same participant stressed that the report narrative and supporting documents would still be required and that the interactive exhibit might not be appropriate in litigation, as it could be difficult to cross examine.

Other participants expressed that some viewers of the interactive 4D exhibit might be suspicious when it is used as evidence and that they would want to interrogate the output to ensure the findings. Yet, others identified that the viewer might trust the interactive 4D exhibit as it is unlikely that the author would go to the extent of creating the 4D model if it was not a fair representation. The same respondents recognised the importance of the 4D model being fact driven, rather than a 4D visualisation, which they described as an interpretation of what occurred on site.

The participants stated that the interactive 4D exhibit was a good attempt at centralising information and that it provided a useful way for the viewer to quickly familiarise themselves with relevant documentation.

Suggested improvements for retrospective analysis

Following on from their review, the focus group participants offered recommendations for improvement. These suggestions are presented against each of the VARK modes of presentation.

Visual improvements for retrospective analysis included:

- Playing the as-planned and then the as-built exhibit after each other, as the side by side comparison can be confusing . Furthermore, the British Standard on epilepsy should be considered.
- Adding detail to the 4D model to make it more realistic. It is too clean, making it difficult to relate to what occurred on site.
- Using colours better, for example delay items could be held in red. This requires colour coding to be explained at the start of the interactive exhibit.
- Zooming into the 4D model on different floors to show problem areas and complex work sequences. An overview of repetitive complex sequences could be presented at the start of the video to show planned intent in a virtual environment.

Audio improvements for retrospective analysis included:

- Improving audio quality. Appropriate hardware and environment should be sought.
- Using a different voice from the person making the claim, as it adds a state of neutrality and reduces confusion. A professional voiceover might be beneficial.

Read/Write improvements for retrospective analysis included:

- Displaying the timeline in a better format. Although the Gantt chart is useful in demonstrating the factual analysis driving the 4D model, it was limited because it could not be easily read.

Kinesthetic improvements for retrospective analysis included:

- Less intrusive or more attractive clickable tags.
- More detailed and relevant information held behind the tags.
- Developing an application to facilitate use on handheld devices.
- Undertaking a poll at the start and/or end of the interactive exhibit to confirm understanding.

4.5.2 NEXT STAGE OF RESEARCH

The next stage for this research is to prepare the findings for publication in a project management journal. Further research could be undertaken to embrace the suggestions for improvement to create a refined concept that assists with understanding delay in dispute resolution.

CHAPTER 5 FINDINGS AND IMPLICATIONS

This final chapter summarises the key findings of the research project and identifies their implications and contribution to knowledge. A critical evaluation is undertaken, recommendations for future work are presented and the chapter finishes with an overall conclusion of the research project.

5.1 KEY RESEARCH FINDINGS

The aim of this research project was to improve the communication of delay on construction projects through BIM. This was achieved through five objectives, which are used as a framework to demonstrate the key research findings.

5.1.1 OBJECTIVE 1: ANALYSING DELAY AND THE APPLICATION OF BIM

This objective was addressed in the literature review published in Paper 1 (Appendix A), which was later updated in Paper 2 (Appendix B) to take into account BIM developments. The publications reported that:

- Two challenges associated with analysing delay are:
  - Retrieving information; and,
  - Communicating the findings.
- These two challenges could be addressed through technology but bespoke software is rarely developed specifically for delay analysis. Instead, technology intended for other purposes is used but this has some limitations, such as:
  - Electronic document management systems centralise information but adequate record keeping processes are not always followed. Therefore, the information does not always exist or it is hard to find; and,
  - CGI’s can help improve communication and understanding of complex problems. CGI’s have been used for contentious issues but they are not always fact driven.
- BIM could address these challenges by:
  - Improving collaboration and processes for managing electronic information. Technology developed to support BIM adoption provides neutral file platforms and allows the coordination of information between different project disciplines; and,
  - Requiring a 3D virtual model which is produced using smart objects. This provides the opportunity for 4D modelling, by linking the graphical model to time related information. This allows the construction sequence to be visualised in a virtual environment.

Further investigation was required to develop these initiatives and to explore the legal implications of BIM.

5.1.2 Objective 2: BIM and construction contracts

This objective was addressed through the content analysis published in Paper 3 (Appendix C). The literature reported that little change was required to current standard forms of construction contract to facilitate a Level 2 BIM environment. However, the research identified that it was not common for BIM to be referenced within standard forms of contract and that legal issues remained a restriction for Level 2 adoption.

Standard forms of construction contract used in the UK were investigated and it was reported that PPC2000 had been used on a UK Government BIM Level 2 trial project without a BIM protocol. However, it was identified that NEC3, JCT and CPC 2013 all require the incorporation of a BIM protocol to support a Level 2 environment. Nevertheless, it was found that all contracts require further consideration if they go beyond Level 2 BIM.

The research identified that CPC 2013 was the only standard form of construction contract to reference BIM in its core clauses and appendices. CPC 2013 was found to partly address the perceived barriers of BIM adoption, which were acknowledged to be legal and contractual; collaboration; use and management of information; and, investment. The research identified that both CPC 2013 and BIM attempted to address delay and disputes in the construction industry but it was recognised that CPC 2013 might require special conditions and amendments to facilitate a true Level 2 BIM environment.

Given that existing standard forms of construction contract were recognised as being able to facilitate a BIM environment, conventional processes for managing and analysing delay could be used. Therefore, further investigation was required to demonstrate how BIM could assist existing practice.

5.1.3 Objective 3: The visual capabilities of BIM to improve understanding about delay

This objective was addressed through the case study published in Paper 4 (Appendix D). The research identified the different values of CGE's and assessed the benefits, limitations and areas for possible improvement for both a 2D and 4D simulation, which were developed to support the same construction delay claim.

Based on these findings, it was recommended that the following items should be considered if CGE's are used to assist with understanding construction delay claims:

- Undertaking a cost benefit analysis to assess the value of the CGE to the claim.
- Determine what's necessary in relation to;
    - Software and expertise; and,
    - Level of detail.
- A side by side comparison of as-planned versus as-built with timeline.
- Communication between the virtual modeller and delay analyst.

Further research was required to test these recommendations in practice.

5.1.4 Objective 4: Developing BIM to manage and analyse delay

This objective was addressed through a workshop and simulation that were published in Paper 5 (Appendix E). The literature review identified that screens were being installed in some courts, which will allow advocates to present evidence straight from their laptop. This opens up opportunities for presenting evidence but it was identified that lawyers needed to rigorously test new technology before it is used for legal purposes. Therefore, multiple stages of assessment needed to be undertaken.

The first stage of assessment, a workshop with experts in construction claims, suggested that CGE's were not commonly used for claim purposes and when they were used, they were not always useful. This supported the findings in Objective 3 (Paper 4, Appendix D). The majority of the workshop participants agreed that CGE's could be improved through VARK modes of presentation and offered suggestions to improve the use of CGE's in dispute resolution.

The second stage of assessment was a simulation based on case study data, which demonstrated how VARK modes of presentation could be integrated into a CGE using an interactive exhibit. However, during development, technology was found to restrict how evenly each of the VARK modes of presentation could be integrated into the interactive exhibit. Furthermore, during the development of the interactive exhibit, there were challenges with software interoperability and balancing the LoD in the construction schedule and the 3D virtual model.

Although this research demonstrated that VARK modes of presentation could be integrated with 4D modelling software that had been developed to support BIM adoption, further research was required to validate how useful the proposed interactive exhibit was in understanding delay.

5.1.5 Objective 5: Validation of proposed concept

The research towards this objective is included in the thesis. Data gathered from the questionnaire demonstrated that 4D modelling has an application at each project stage but none of the respondents had experience using 4D modelling throughout the lifecycle of a project. Therefore, it is unclear whether construction projects using 4D modelling are adopting it across all project stages. Furthermore, the standard of 4D models varied between respondents but it remains unclear whether this is due to the skill of the workforce or the project's requirements.

The focus group recognised the value of VARK modes of presentation for time management. However, the participants did not think the proposed interactive exhibit was appropriate for pro-active management because the process was closed and slow. Conversely, the focus group saw value in the interactive exhibit for retrospective analysis and tendering.

One of the workshop participants had used 4D modelling for construction claims and, in the correct situation, encouraged other workshop members to utilise it for these purposes. The same participant stressed the need for supporting documents to drive the model, as some viewers might be suspicious of the CGE. Therefore, the interactive exhibit should not replace the conventional documents required to support construction claims; instead, the proposed concept could be used as a supporting tool for these documents. This finding echoed the data collected in Objective 4 (Paper 5, Appendix E) and the workshops suggestions for improvement to the interactive exhibit could be developed as further research.

5.2 IMPLICATIONS OF FINDINGS AND CONTRIBUTION TO KNOWLEDGE

5.2.1 EXISTING THEORY AND PRACTICE

The findings of this research project are summarised into four original contributions to existing theory and practice.

Linking BIM literature with claim and dispute literature to address delay challenges

The literature suggested that BIM could reduce the number of delays and disputes in the industry, yet it did not identify how this could be achieved. Published work linking BIM with delay claims and disputes was limited, so this was addressed through a comprehensive literature review that combined the two disciplines. Within this literature review, the challenges faced by delay analysts were identified and succinctly reported, which appeared absent in the existing literature. The opportunity for BIM to address the challenges was presented (Paper 1, Appendix A) and based on these findings, suggestions about the practical impact of BIM on future claims and disputes were published (Paper 2, Appendix B).

Recommendations when using 4D modelling to assist delay claims and disputes

The use of 4D modelling is rising but to the RE's knowledge, this was the first published research that critically analysed how 4D modelling had been used in dispute resolution (Paper 4, Appendix D). The findings demonstrated the need to improve how 4D modelling is being used in delay claims and disputes, and provided recommendations to assist with its practical application. The need for these recommendations was reiterated in subsequent data collection, where dispute resolution experts suggested that CGE's were rarely used but when they were, they were not always useful in assisting understanding (Paper 5, Appendix E). During this data gathering process, the participants shared recommendations for improvement, which were found to overlap with the previous findings (Paper 4, Appendix D). This reaffirmed the value of the original recommendations, which were developed and applied to a dispute to demonstrate practical application (Paper 5, Appendix E).

Integrating VARK modes of presentation with technology to improve understanding about delay

Through an interactive exhibit, the research demonstrated how VARK modes of presentation could be integrated with technology. No other published research has been found, in any industry, which makes this connection. More specific to the construction industry, within this research project, the application of an interactive exhibit for managing and analysing delay has been developed (Paper 5, Appendix E) and its practical application was validated through expert review (Section 4.5). It is recognised that the application of VARK modes of presentation with technology could benefit other aspects of the construction industry.

Demonstrating how CPC 2013 can facilitate a BIM environment

Detailed reviews of how specific standard forms of construction contract facilitate a BIM environment are limited, especially in relation to addressing the perceived barriers restricting BIM adoption. As a relatively new contract, the literature surrounding CPC 2013 is also limited. Therefore, the research on how CPC 2013's clauses and appendices practically address the perceived barriers was novel (Paper 3, Appendix C) and the approach could be reused to assess how other standard forms of construction contract facilitate a BIM environment.

5.2.2 INDUSTRIAL SPONSOR

This section reflects on the industrial sponsors need for research (Section 1.4.1) and demonstrates the implications of the research findings and contribution to knowledge to the sponsoring organisation.

BIM and 4D modelling proposals

The RE practically employed the knowledge gained in the research project to produce a plan to integrate IT and BIM into project management services for a 5 year+ oil and gas real estate construction and maintenance contract across 5 territories. This required the RE to collaborate across different time zones with senior members of staff to understand the internal IT and BIM capabilities of each territory. The RE was then selected to represent the sponsoring organisation at interview with the client. In addition to this, on a separate project, the RE provided consulting services for the implementation of an innovate approach to 4D modelling across a £40billion+ rail project.

Business development

This research has helped position the sponsoring organisation at the forefront of understanding how BIM can assist construction claims and disputes. Numerous meetings were held with clients in the UK and Ireland to spread the knowledge gained throughout this research project, such as presentations at law firms. The RE also represented the sponsoring organisation at company promoted events, such as Masterclasses and law forums, presenting on the topics of BIM and 4D modelling for claims and dispute resolution. Furthermore, the RE collaborated with colleagues to produce literature, such as the use of electronic document management systems to recover construction records (Wilks, 2015).

Raised awareness through knowledge sharing

Following the release of the UK Government's BIM mandate, it was unclear how BIM might affect construction disputes. Having a staff member with expertise in BIM provided the sponsoring organisation with greater confidence in winning and undertaking BIM work. To assist in staff development, the RE shared knowledge about the core documents and processes related to "Level 2" BIM. This was undertaken across the sponsoring organisation through literature, presentations and meetings, such as a training session on BIM and CPC 2013 with representatives from Hill International's offices in the Middle East. This provided the sponsoring organisation, as a whole, with greater certainty about what to expect on future BIM disputes.

The knowledge and experience in technology supporting 4D modelling, as well as talking with industry experts about the changing nature of scheduling, was continually reported to the delay team to keep them up to date with industry developments. The research also provided greater confidence in using 4D modelling to support dispute resolution, which included interest from offices in Asia-Pacific.

5.2.3 WIDER INDUSTRY

This research should assist the wider industry in their production of 4D models. This is pertinent given that this research found that the production of 4D models for claim and dispute purposes was not always well performed. Furthermore, the application of modes of presentation with technology to assist with managing and analysing delay is an approach not previously considered by the industry. It may also be possible for the benefits of interactive videos to extend beyond delay claims and disputes. In addition to the publications appended to this document and the work undertaken for the sponsoring organisation, the research findings were shared with the wider industry in the following three ways.

Professional institutions (CPD events)

Co-presented with Industrial Supervisor on the topic of BIM and CPC 2013 for the SCL and CIOB. Another co-presentation was given to the CIOB with Freeform3D about using 4D modelling as an input (process) for pro-active control, rather than just as a visual output. A further presentation was given at Arbrix to inform RICS adjudicators about BIM and the opportunity to use modes of presentation with 4D modelling to improve understanding about construction delay disputes.

4D users group

Acting as a core member of a 4D users group to assist knowledge sharing between group members and the wider industry. The 4D users group consists of over 50 members, including clients, contractors, architects, consultants and software developers. The findings of this research project have been presented to the 4D users group, raising their awareness of the application of BIM and 4D modelling for delay claims and disputes, as well as providing ideas for future development and application. This includes ongoing developments to integrate 4D modelling with virtual reality.

Peer review and contributing author

As a contributing author to the book Delay and Disruption in Construction Contracts (Burr, 2016), some of the research findings have appeared alongside influential authors in the field of construction law. In its fifth edition, the book is reputable within the construction law community, so it is hoped that the work will be read by the wider industry. The knowledge gained throughout the research project has also allowed the RE to review journal manuscripts relating to BIM for Institution of Civil Engineers (ICE) Forensic Engineering; Architectural Engineering and Design Management (AEDM); and, Information Technology in Construction (ITCon). This has allowed the RE to share their knowledge of BIM with individuals who have similar interests.

5.3 CRITICAL EVALUATION OF THE RESEARCH

Although this project addresses the research aim, which is improving the understanding of delay on construction projects through BIM, no research is without its limitations. This section presents some of the main challenges the research faced in relation to scope, process and data. Suggestions on overcoming these limitations for future research are also included.

5.3.1 SCOPE OF THE RESEARCH

This section relates to research scope and constraints presented in Section 1.5. The initial research scope was established after the publication the UK Construction Strategy (Cabinet Office, 2011) and at that point in time, documentation supporting the adoption of BIM was pending publication. It was anticipated that there would be growth in the adoption of BIM on construction projects following the publication of these documents and that the research project would have access to BIM project data.

Although there has been reported growth in the adoption of BIM on UK construction projects, the industrial sponsor has not encountered a BIM project. This could be attributed to their primary focus on contentious issues. Best efforts were made to gain experience on BIM projects through external organisations, but these organisations were hesitant to provide access to their BIM projects. This might have been attributed to the organisations wanting to maintain a competitive advantage, or that the organisations were not as advanced as they stated.

As a consequence, project data was limited to the sponsoring organisation. This resulted in an emphasis on retrospective delay analysis for dispute resolution, with limited practical experience in the pro-active management of time on construction projects. Therefore, given the EngD's requirements to provide a practical solution to the problems faced by the industrial sponsor, the research tended to be skewed towards retrospective delay analysis. This may have contributed to the reason why the interactive exhibit (Paper 5, Appendix E) had a greater application for dispute resolution than for the pro-active management of delay (Section 4.5).

For future research projects, it is suggested that research focuses on either retrospective delay analysis or the pro-active management of time, as providing a holistic solution for both is challenging.

5.3.2 RESEARCH PROCESS

At the inception of the research project, expertise that bridged BIM and construction delays were limited. While this gave the RE the opportunity to become an expert in the field, a point of reference was not available for advice on topics that spanned the two disciplines.

The nature of construction disputes can generate a high pressure environment and require long term involvement, so the execution of this research project required a sustained balance between industrial and academic requirements. Best efforts were made to experience the practical problems faced by delay analyst whilst also fulfilling the academic rigour required to research and publish the findings. However, the time allocation between industrial and academic work was not always evenly split and fluctuated throughout the research project. This was especially true when the RE was subcontracted to Hill International. Whilst the additional experience offered by Hill International was invaluable, the move caused some disruption and slowed down the progress of the research when the RE initially joined. The change in supervisors also caused a little disruption, with Hill International taking on an industrial supervisor's role and the lead academic supervisor moving to another university.

Ideally, the project criteria would not alter but as emphasised throughout this document, all projects encounter change. The changes on this project were well controlled, resulting in minimal disruption. Furthermore, the lack of specific expertise was viewed as more of an opportunity than a hindrance. Therefore, in the future, it is suggested that a similar approach to management is followed on research projects experiencing similar changes.

5.3.3 VALIDITY AND RELIABILITY OF THE DATA

As a new research area, no data existed which bridged BIM and delay. Furthermore, the sensitive nature and limited access to dispute resolution data made the collection of data more challenging. This section presents some of the limitations of the data used to address each objective.

Objective 1: Analysing delay and the application of BIM – Literature review

The literature is constantly evolving, especially for BIM. The initial findings presented in Paper 1 (Appendix A) were updated with literature developments and published in Paper 2 (Appendix B). However, since the publication of this second paper, literature that is more influential has emerged, such as Rider 1, which removes preference for the time impact analysis when analysing delay (SCL, 2015). These influential publications have been included in the literature review of this thesis (Chapter 2) and as time passes, efforts should be made to continual review the literature on BIM and delay analysis.

Objective 2: BIM and construction contracts – Content analysis

The RE maintains that a content analysis was the most appropriate way to investigate CPC 2013 in Paper 3 (Appendix C). However, the barriers against BIM adoption, which were used as a framework to guide the research analysis, could have been determined from primary data, such as interviews with experts. Yet, at the time of research, industry awareness of CPC 2013, as well as the contractual requirements for BIM, were limited. Therefore, data from industry experts could be included in future research, when awareness of the subject areas has increased.

Objective 3: The visual capabilities of BIM to improve understanding about delay – Case study

Data on the use of CGE’s for construction delay disputes is not widely available, so the case study presented in Paper 4 (Appendix D) provides a valuable insight into this area. However, the researcher did not have first-hand experience of the dispute and could only report on the available documents and the knowledge gained from individuals involved with the delay analysis. However, as is common with many disputes, the project records available were limited. Due to the sensitive nature of the dispute, these opinions could not be reported through survey data and specific details, such as the cost of the CGE and location of the project, had to be omitted or anonymised. While this did not compromise the findings, it distanced the context. Therefore, where possible, there would be value in adding more contextual detail to future publications.

Objective 4: Developing BIM to manage and analyse delay – Workshop and simulation

A workshop was chosen because access to this many experts at one time is limited. The 50 workshop participants were forthcoming with their opinions and voting ensured that data was captured from everyone (Paper 5, Appendix E). However, the workshop’s size and time limit restricted the opportunity for all participants to contribute to the discussion, so the research could benefit from supplementary interviews. In the future, there would be value in a smaller number of participants and a longer duration, but care should be taken not to compromise the number of willing respondents.

To heighten the value of the simulation, case study data was included from a delay dispute. Time was lost converting the data into a suitable format for the 4D modelling software and modifications and checks were required to ensure the integrity of the reported delay analysis. Although only a single “window” was published, the complete schedule had to be checked to ensure the analysis was reacting correctly. This highlighted the challenges of 4D modelling interoperability and in the future, it is recommended that the chosen scheduling software is directly compatible with the 4D modelling software.

Objective 5: Validation of proposed concept – Questionnaire and focus group

The questionnaire helped provide context for the focus group discussion but it could have benefited from asking whether the participants had worked on projects that utilised 4D modelling throughout its lifecycle.

The findings of the focus group provided useful recommendations to improve the interactive exhibit. However, like the workshop used for data collection in Objective 4, the sample size was large and the time was limited. The focus groups attendance was unexpectedly high, so in the future it is recommended to hold multiple workshops with smaller numbers of participants. Given the increasing use and advancements in 4D modelling, it would be interested to monitor this development in future research.

5.4 RECOMMENDATIONS FOR FUTURE RESEARCH

The link between BIM and delay is a relatively new field, which opens up the possibility for numerous research opportunities. Some of these opportunities were investigated as the research developed (Chapter 4) and others are recognised as ways to enhance data collection (Section 5.3.3).

It is hoped that this research will encourage further collaboration between industry and academia to investigate BIM and delay. Areas to consider include:

Development of BIM to assist with the storage and retrieval of delay information

Objective 1 identified that delay analysts face the challenge of 1) retrieving project information; and, 2) communicating their findings. While this research has addressed how BIM can assist with communicating the findings of delay analysis, the challenge of information retrieval remains. Further research could investigate how the software developed to support BIM could be used to store delay information and how it could be accessed and utilised to assist with delay analysis.

BIM and construction contracts

Although Objective 2 broadly investigated some of the standard forms of construction contract used in the UK, it focused on CPC 2013. There would be value in performing a similar comprehensive review of other standard forms of construction contract, which could follow the framework established in Paper 3 (Appendix C). There would also be value in undertaking a comprehensive review of BIM protocols, given that current standard forms of construction contract require their inclusion. This could include investigating risk allocation, especially as collaboration requirements increase.

Application of VARK modes of presentation and interactive videos within the construction industry

The application of VARK modes of presentation and interactive videos within the construction industry are not currently published. Research could use VARK to improve the communication of information in areas such as Health and Safety. Interactive videos could also add value to other construction stages, such as for tendering purposes. Further developments are also required to improve how interactive videos and VARK modes of presentation could assist with time management.

Improve the application of VARK modes of presentation for disputes using developments in technology

There would be value in research that sought to integrate VARK modes of presentation within 4D modelling software. This would address the need for video format and improve the opportunity for interrogation, which acts as a limitation (Paper 5, Appendix E). Research that considers the use of virtual or augmented reality to enhance VARK modes of presentation could also be useful. Legal research into the admissibility of interactive exhibits and other technological developments for different dispute resolution techniques, as well as the proportionality of investment, would also be of interest.

Ongoing research

Work is currently being undertaken by the RE to improve the communication of 4D models for proactive control, with a focus on dashboards and virtual reality. The RE is also contributing work on the value of 4D modelling at different project stages and the information required to develop certain standards of 4D models. Progress is also being made to publish the findings of Objective 5 in a project management journal.

5.5 CONCLUDING REMARKS

This research project achieved its aim by providing a novel way of understanding delay through BIM. The five objectives undertaken to address the aim have established a link between BIM and delay dispute literature; provided recommendations on using 4D modelling software developed to support BIM adoption to assist with delay disputes; integrated VARK modes of presentation with technology to improve the understanding of delay; and, demonstrated how construction contracts facilitate a BIM environment. Collectively, these findings supported the development of the proposed interactive exhibit, which industry experts identified as having the potential to improve the understanding of delay on construction projects. As BIM adoption continues to grow around the world, the supporting technology and processes can be used to assist with pro-active time management and ease the effort required to create CGE's, which are becoming more widely accepted by the legal community to assist with understanding complex disputes.

REFERENCES

List of Cases

AMEC Civil Engineering Ltd v. Secretary of State for Transport [2005] EWCA Civ 291

Hadley v. Baxendale [1854] EWHC Exch J70 Courts of Exchequer

Halki Shipping Corporation v. Sopex Oils Ltd [1998] 1 WLR CA

Miliangos v. George Frank [1976] AC 443

People v. Mitchell [1964] 61 Cal.2d 353

Racz v. R.T. Merryman Trucking [1994] WL 124857

Regional Construction Sdn. Bhd. v. Chung Syn Kheng Electrical Co. Bhd. [1987] 2 MLJ 763

Robinson v. Harman [1848] 1 Ex 850

Walter Lilly and Company Ltd v. Mackay and Anor [2012] EWHC 1773

Works Cited

AACE. (2007). *Forensic Schedule Analysis: AACE International Recommended Practice No. 29R-03*. Morgantown: Association for the Advancement of Cost Engineering International.

Ammar, M. (2013). LOB and CPM Integrated Method for Scheduling Repetitive Projects. *Journal of Construction Engineering and Management*, 139(1), pp.44-50.

Arcadis. (2015). *Global construction dispute report 2015: The higher the stakes, the bigger the risk*. Amsterdam: Arcadis.

Arditi, D. and Albulak, M. (1986). Line-of-Balance Scheduling in Pavement Construction. *Journal of Construction Engineering and Management*, 112(3), pp.411-424.

Arditi, D., Tokdemir, O. and Suh, K. (2002). Challenges in Line-of-Balance Scheduling. *Journal of Construction Engineering and Management*, 128(6), pp.545-556.

Bailey, J. (2014). The Society of Construction Law Delay and Disruption Protocol: A Retrospective Analysis. *Society of Construction Law*, 189.

Barry, D. (2013). The SCL Delay and Disruption Protocol – 10 years on. *Construction Law Journal*, 29(5), pp.367-368.

Bayraktar, M., Arif, F., Hastak, M. and Gad, N. (2012). Judiciary's Use of the Critical Path Method to Resolve Construction Claims. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 4(1), pp.10-16.

BIM Forum. (2015). *Level of Development Specification for Building Information Models*. Washington: BIM Forum.

Blaikie, N. (2007). *Approaches to Social Enquiry: Advancing Knowledge*. 2nd ed. Cambridge: Polity Press.

Boynton, P. (2004). Administering, analysing, and reporting your questionnaire. *BMJ*, 328(7452), pp.1372-1375.

Braimah, N. (2013). Construction Delay Analysis Techniques—A Review of Application Issues and Improvement Needs. *Buildings*, 3(3), pp.506-531.

Brown, G. and Edmunds, S. (2011). *Doing pedagogical research in engineering*. Loughborough: Loughborough University.

Bryde, D., Broquetas, M. and Volm, J. (2013). The project benefits of Building Information Modelling (BIM). *International Journal of Project Management*, 31(7), pp.971-980.

Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative Research*, 6(1), pp.97-113.

Bryman, A. (2012). *Social research methods*. 4th ed Oxford: Oxford University Press.

BSI (British Standard Institution). (2000). BS 6079-2:2000. *Guide to Project Management – Vocabulary*.

BSI (British Standard Institution). (2007). BS 1192:2007. *Collaborative production of architectural, engineering and construction information – Code of practice*.

BSI (British Standard Institution). (2014). BS 1192-4:2014. *Collaborative production of information Part 4: Fulfilling employer's information exchange requirements using COBie – Code of practice*.

Burr, A. (2016). *Delay and Disruption in Construction Contracts*. 5th ed. Abingdon: Informa Law from Routledge.

Cabinet Office. (2011). *Government construction strategy May 2011.* London: Cabinet Office.

Cabinet Office. (2012). *Government Soft Landings: Section 1 – Introduction*. London: Cabinet Office.

Ceglinski, J. (2013). Admitting Animations: Applied Psychology Research as a Call for Improved Guidance in Assessing the Prejudicial Impact of Computer-Generated Animations. *Drexel Law Review*, 6, pp.177-213.

Chau, K., Anson, M. and Zhang, J. (2003). Implementation of visualization as planning and scheduling tool in construction. *Building and Environment*, 38(5), pp.713-719.

Chiu, C. and Russell, A. (2011). Design of a construction management data visualization environment: A top–down approach. *Automation in Construction*, 20(4), pp.399-417.

Chiu, C. and Russell, A. (2013). Design of a construction management data visualization environment: A bottom-up approach. *Automation in Construction*, 35, pp.353-373.

Chrzanowski, E. and Johnston, D. (1986). Application of Linear Scheduling. *Journal of Construction Engineering and Management*, 112(4), pp.476-491.

CIC (Construction Industry Council). (2013). *Building Information Model (BIM) Protocol*. London: Construction Industry Council.

CIC (Construction Industry Council). (2014). *Built Environment 2050: A Report on Our Digital Future*. London: Construction Industry Council.

CIOB (Chartered Institute of Building). (2011). *Guide to good practice in the management of time in complex projects*. New Jersey: John Wiley-Blackwell.

CIOB (The Chartered Institute of Building). (2008). *Managing the risk of delayed completion in the 21st century*. Berkshire: The Chartered Institute of Building.

Cole, L. (1991). Construction Scheduling: Principles, Practices, and Six Case Studies. *Journal of Construction Engineering and Management*, 117(4), pp.579-588.

Comyns, J. and Hammond, A. (1822). *A digest of the laws of England*. London: Printed by A. Strahan for Joseph Butterworth and Son.

Conlin, J. (1997). The applicability of project management software and advanced IT techniques in construction delays mitigation. *International Journal of Project Management*, 15(2), pp.107-120.

Cooke, B. and Williams, P. (2009). *Construction planning, programming and control*. 3rd ed. Chichester: Wiley-Blackwell.

Creswell, J. (2014). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*. 4th ed. California: SAGE publications.

Critchlow, J., Farr, A., Briggs, S., Hammond, J., Pickavance, K. and Lavers, A. (2006). The Great Delay Analysis Debate. *Society of Construction Law*, 130.

D'Onofrio, M. and Hoshino, K. (2010). AACE Recommended Practice for Forensic Schedule Analysis. *The 2010 Annual Meeting the Age of Turbulence: Managing Money Issues in Construction, Austin, 22-24 April, 2010*. American Bar Association Forum on the Construction Industry.

Dawood, N. and Sikka, S. (2009). Development of 4D based performance indicators in construction industry. *Engineering, Construction and Architectural Management*, 16(5), pp.438-458.

Denning, J. and Verschelden, C. (1993). Using the focus group in assessing training needs: Empowering child welfare workers. *Child Welfare: Journal of Policy, Practice, and Program*, 72(6), pp.569-579.

Denzin, N. and Lincoln, Y. (2005). *The SAGE Handbook of Qualitative Research*. 3rd ed. California: SAGE Publications.

Ding, L., Zhou, Y. and Akinci, B. (2014). Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD. *Automation in Construction*, 46, pp.82-93.

Dougherty, J. (2015). *Claims, Disputes and Lititgation Involving BIM*. Abingdon: Routledge.

Drummond, F., Sharp, L., Carsin, A., Kelleher, T. and Comber, H. (2008). Questionnaire order significantly increased response to a postal survey sent to primary care physicians. *Journal of Clinical Epidemiology*, 61(2), pp.177-185.

Dvir, D. and Lechler, T. (2004). Plans are nothing, changing plans is everything: the impact of changes on project success. *Research policy*, 33, pp.1-15.

Easterby-Smith, M., Thorpe, R. and Lowe, A. (2002). *Management Research: An introduction*. 2nd ed. London: SAGE publications.

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*. 2nd ed. New Jersey: Wiley and Sons.

Egan, J. (1998). *Rethinking construction*. London: Department of Trade and Industry.

Eggleston, B. (2009). *Liquidated Damages and Extensions of Time: In Construction Contracts.* 3rd ed. Chichester: John Wiley and Sons.

Ehle, B. (2012). Effective Use of Demonstrative Exhibits in International Arbitration. *Czech (and Central European) Yearbook of Arbitration*, pp.43-59.

Fallowfield, L. (1995). Questionnaire design. *Archives of Disease in Childhood*, 72(1), pp.76-79.

Farmer, M. (2017). *The Farmer review of the UK construction labour model: Modernise or die, Time to decide the industry's future*. London: Construction Leadership Council.

Farrow, T. (2001). Delay analysis – methodology and mythology. *Society of Construction Law*, 98.

Farzad Moosavi, S. and Moselhi, O. (2014). Review of Detailed Schedules in Building Construction. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 6(3), pp.05014001.

Feigenson, N. and Spiesel, C. (2009). *Law on display*. New York: New York University Press.

Fellows, R. and Liu, A. (2008). *Research Methods for Construction*. 3rd ed. Chichester: Blackwell.

Fenby-Talor, H., Thompson, N., Philp, D., MacLaren, A., Rossiter, D. and Bartley, T. (2016). *Scotland BIM Study*. Edinburgh: Heriot-Watt University.

Fischer, M., Haymaker, J. and Liston, K. (2003). Benefits of 3D and 4D models for facility managers and AEC service providers. *In*: R. Issa, I. Flood and W. O'Brien, ed. *4D CAD and Visualization in Construction: Developments and Applications*. Lisse: Swets and Zeitlinger, 2003, pp.1-32.

Fisher, R. (2004). The Problem-Solving Workshop as a Method of Research. *International Negotiation*, 9(3), pp.385-396.

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, 12(2), pp.219-245.

Fondahl, W. (1962). *A non-computer approach to the critical path method for the construction industry*. 2nd ed. California: Stanford university.

Froese, T. (2010). The impact of emerging information technology on project management for construction. *Automation in Construction*, 19(5), pp.531-538.

Given, L. (2008). *The SAGE encyclopedia of qualitative research methods*. Los Angeles: SAGE publications.

Golparvar-Fard, M., Peña-Mora, F., Arboleda, C. and Lee, S. (2009). Visualization of Construction Progress Monitoring with 4D Simulation Model Overlaid on Time-Lapsed Photographs. *Journal of Comuputing in Civil Engineering*, 23(6), pp.391-404.

Greene, J., Caracelli, V. and Graham, W. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis*, 11(3), pp.255-274.

Haidar, A. and Barnes, P. (2011). *Delay and disruption claims in construction*. London: ICE.

Han, K., Cline, D. and Golparvar-Fard, M. (2015). Formalized knowledge of construction sequence for visual monitoring of works-in-progress via incomplete point clouds and low-LoD 4D BIMs. *Advanced Engineering Informatics*, 29(4), pp.889-901.

Harris, F. and McCaffer, R. (2013). *Modern Construction Management*. 7th ed. Chichester: Wiley-Blackwell.

Hartmann, T., Gao, J. and Fischer, M. (2008). Areas of Application for 3D and 4D Models on Construction Projects. *Journal of Construction Engineering and Management*, 134(10), pp.776-785.

Hartmann, T., Meerveld, H., Vossebeld, N. and Adriaanse, A. (2012). Aligning building information modelling tools and construction management methods. *Automation in Construction*, 22, pp.605-613.

Hedeker, D. and Gibbons, R. (2006). *Longitudinal data analysis*. New Jersey: Wiley-Interscience.

Heesom, D. and Mahdjoubi, L. (2004). Trends of 4D CAD applications for construction planning. *Construction Management and Economics*, 22(2), pp.171-182.

Henver, A., March, S., Park, J. and Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, 28(1), pp.75-105.

HM Government. (2013). *Construction 2025. Industrial Strategy: government and industry in partnership*. London: Crown

HM Government. (2015). *Digital Built Britain: Level 3 Building Information Modelling—Strategic Plan*. London: Crown.

Householder, J. and Rutland, H. (1990). Who owns float? *Journal of Construction Engineering and Management*, 116(1), pp.130-133.

Hsieh, H. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research*, 15(9), pp.1277-1288.

Hughes, D. and DuMont, K. (1993). Using focus groups to facilitate culturally anchored research. *American Journal of Community Psychology*, 21(6), pp.775-806.

Ibbs, C., Wong, C. and Kwak, Y. (2001). Project change management system. *Journal of Management in Engineering*, 17(3), pp.159-165.

Infrastructure and Project Authority. (2016). *Government construction strategy 2016-20*. London: Cabinet Office.

Ioannou, P. and Yang, I. (2016). Repetitive Scheduling Method: Requirements, Modeling, and Implementation. *Journal of Construction Engineering and Management*, 142(5), pp.04016002.

JBKnowledge. (2015). *The 4th Annual Construction Technology Report*. Texas: JBKnowledge.

Jongeling, R. and Olofsson, T. (2007). A method for planning of work-flow by combined use of location based scheduling and 4D CAD. *Automation in Construction*, 16, pp.189-198.

Kangari, R. (1995). Construction Documentation in Arbitration. *Journal of Construction Engineering and Management*, 121(2), pp.201-208.

Kassem, M., Brogden, T. and Dawood, N. (2012). BIM and 4D planning: a holistic study of the barriers and drivers to widespread adoption. *KICEM Journal of Construction Engineering and Project Management*, pp.1-10.

KCL (Kings College London). (2016). *Enabling BIM through procurement and contracts*. London: Kings College London.

Keane, P. and Caletka, A. (2008). *Delay analysis in construction*. Oxford: Blackwell.

Keim, D., Mansmann, F., Schneidewind, J. and Ziegler, H. (2006). Challenges in visual data analysis. In: *Tenth International Conference on Information Visualisation (IV'06), London, 5-7 July, 2006*. California: IEEE Computer Society, pp.9-16.

Kelley, J. (1961). Critical-Path Planning and Scheduling: Mathematical Basis. *Operations Research*, 9(3), pp.296-320.

Khatib, J., Chileshe, N. and Sloan, S. (2007). Antecedents and benefits of 3D and 4D modelling for construction planners. *Journal of Engineering, Design and Technology*, 5(2), pp.159-172.

Kitzinger, J. (1994). The methodology of Focus Groups: the importance of interaction between research participants. *Sociology of Health and Illness*, 16(1), pp.103-121.

Kitzinger, J. (1995). Qualitative Research: Introducing focus groups. *BMJ*, 311(7000), pp.299-302.

Koo, B. and Fischer, M. (2000). Feasibility Study of 4D CAD in Commercial Construction. *Journal of Construction Engineering and Management*, 126(4), pp.251-260.

Kothari, C. (2009). *Research methodology*. 2nd ed. New Delhi: New Age International.

Krieger, R. (1992). Sophisticated computer graphics come of age – and evidence will never be the same. *American Bar Associations Journal,* December, pp.92-95.

Krippendorff, K. (2010). Content analysis. *In*: N. Salkind, ed. *Encyclopedia of research design*. California: SAGE publications, 2010, pp.234-239.

Krueger, R. and Casey, M. (2015). *Focus groups: a practical guide for applied research*. 5th ed. New Delhi: SAGE publications.

Kuechler, W. and Vaishnavi, V. (2011). Promoting Relevance in IS Research: An Informing System for Design Science Research. *Informing Science: The International Journal of an Emerging Transdiscipline*, 14(1), pp.125-138.

Kuechler, W. and Vaishnavi, V. (2012). A Framework for Theory Development in Design Science Research: Multiple Perspectives. *Journal of the Association for Information Systems*, 13(6), pp.395-423.

Kumar, C. (2008). *Research methodology*. New Delhi: APH.

Kumaraswamy, M. (1997). Conflicts, claims and disputes in construction. *Engineering, Construction and Architectural Management*, 4(2), pp.95-111.

Latham, M. (1994). *Constructing the team*. London: HMSO.

Lazarus, D., and Clifton, R. (2001). *Managing project change: A best practice guide*. Westminster: Construction Industry Research and Information Association (CIRIA).

Lederer, F. (1994). Technology Comes to the Courtroom, and... *Emory Law Journal*, 43, pp.1095-1122.

Lee, N. and Rojas, E. (2013). Visual Representations for Monitoring Project Performance: Developing Novel Prototypes for Improved Communication. *Journal of Construction Engineering and Management*, 139(8), pp.994-1005.

Lee, N. and Rojas, E. (2010). Defining High-Level Project Control Data for Visual Information Systems. In: *Construction Research Congress 2010: Innovation for Reshaping Construction Practice, Alberta, 8-10 May, 2010*. American Society of Civil Engineers, pp. 518-527.

Leech, N. and Onwuegbuzie, A. (2009). A typology of mixed methods research designs. *Quality and Quantity*, 43(2), pp.265-275.

Lifschitz, J., Barba, E. and Lockshin, A. (2009). A Critical Review of the AACEI Recommended Practice for Forensic Schedule Analysis. *The Construction Lawyer*, 29(4), pp.15-47.

Liston, K., Fischer, M. and Winograd, T. (2001). Focused sharing of information for multidisciplinary decision making by project teams. *ITcon*, 6, pp.69-82.

Love, P., Davis, P., Ellis, J. and On Cheung, S. (2010). Dispute causation: identification of pathogenic influences in construction. *Engineering, Construction and Architectural Management*, 17(4), pp.404-423.

Love, P., Holt, G., Shen, L., Li, H. and Irani, Z. (2002). Using systems dynamics to better understand change and rework in construction project management systems. *International Journal of Project Management*, 20, pp.425-436.

Lutz, J. and Hijazi, A. (1993). Planning repetitive construction: Current practice. *Construction Management and Economics*, 11(2), pp.99-110.

Mahalingam, A., Kashyap, R. and Mahajan, C. (2010). An evaluation of the applicability of 4D CAD on construction projects. *Automation in Construction*, 19(2), pp.148-159.

Mastrandrea, F. (2014). Concurrent delay in construction – principles and challenges. *The International Construction Law Review*, pp.83-107.

Mattila, K. and Abraham, D. (1998). Linear scheduling: past research efforts and future directions. *Engineering, Construction and Architectural Management*, 5(3), pp.294-303.

Mattila, K. and Park, A. (2003). Comparison of Linear Scheduling Model and Repetitive Scheduling Method. *Journal of Construction Engineering and Management*, 129(1), pp.56-64.

Mawdesley, M., Askew, W. and O'Reilly, M. (1997). *Planning and controlling construction projects*. Essex: Longman.

McGraw Hill. (2014). The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation with Building Information Modeling. *SmartMarket Report*.

McKinney, K. and Fischer, M. (1998). Generating, evaluating and visualizing construction schedules with CAD tools. *Automation in Construction*, 7(6), pp.433-447.

McKinsey. (2017). *Reinventing construction: a route to higher productivity.* London: McKinsey Global Institute.

McNaught, M. and Lam, P. (2010). Using Wordle as a Supplementary Research Tool. *The Qualitative Report*, 15(3), pp.630-643.

Morgan, D. (1988). *Focus Groups as Qualitative Research*. California: SAGE publications.

NAO (National Audit Office). (2001). *Modernising Construction: Report by the controller and auditor general HC 87 Session 2000-2001: 11 January 2001*. London: The Stationery Office.

Naoum, S. (2013). *Dissertation research and writing for construction students*. 3rd ed. New York: Routledge.

National Academies. (2009). *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry*. Washington: The National Academies Press.

NBS (National Building Specification). (2014). *NBS international BIM report 2013*. London: RIBA Enterprises.

NBS (National Building Specification). (2015a). *National Construction Contracts and Law Survey 2015.* London: RIBA Enterprises.

NBS (National Building Specification). (2015b). *NBS BIM report 2015*. London: RIBA Enterprises

Noond, J., Schofield, D., March, J. and Evison, M. (2002). Visualising the scene: computer graphics and evidence presentation. *Science and Justice*, 4*2*(2), pp.89-95

O'Flaherty, D. (1996). Computer-Generated Displays in the Courtroom: For Better or Worse? *Web Journal of Current Legal Issues*, 2(4).

OGC (Office of Government Commerce). (2009). *Managing Successful Projects with PRINCE2*. 5th ed. London: The Stationary Office.

PAS (Publicly Available Specification). (2013). PAS 1192-2:2013 Incorporating Corrigendum No.1. *Specification for information management for the capital/delivery phase of construction projects using building information modelling*.

PAS (Publicly Available Specification). (2014). PAS 1992-3:2014 Incorporating Corrigendum No.1. *Specification for information management for the operational phase of assets using building information modelling*.

PAS (Publicly Available Specification). (2015). PAS 1992-5:2015. *Specification for security-minded building information modelling, digital built environments and smart asset management*.

Pickavance, K. (2004). Putting the SCL Delay and Disruption Protocol into Practice – is it what the industry wants? *Society of Construction Law*, D052.

Pickavance, K. (2007a). *Construction Law and Management*. London: Informa Law.

Pickavance, K. (2007b). Using advanced forensic animations to resolve complex disruption claims. *Society of Construction Law*, D87.

Pickavance, K. (2010). *Delay and Disruption in Construction Contracts*. 4th ed. London: Sweet and Maxwell.

Powell, R. and Single, H. (1996). Focus Groups. *International Journal for Quality in Health Care*, 8(5), pp.499-504.

Presser, S., Couper, M., Lessler, J., Martin, E., Martin, J., Rothgeb, J. and Singer, E. (2004). Methods for testing and evaluating survey questions. *Public opinion quarterly*, 68(1), pp.109-130.

Puchta, C. and Potter, J. (1999). Asking elaborate questions: Focus groups and the management of spontaneity. *Journal of Sociolinguistics*, 3(3), pp.314-335.

Ramanathan, C., Narayanan, S. and Idrus, A. (2012). Construction delays causing risks on time and cost - a critical review. *Australasian Journal of Construction Economics and Building*, 12(1), pp.37-57.

Reid, A. and Ellis, R. (2007). Common sense applied to the definition of a dispute. *Structural Survey*, 25(3/4), pp.239-252.

Retik A., Warszawaski A, and Banai A. (1990). The use of computer graphics as a scheduling tool. *Building and Environment*, 25(2), pp.132-142.

RIBA (Royal Institute of British Architects). (2012). *BIM overlay to the RIBA outline plan of work*. London: RIBA Enterprises.

Robson, C. (2011). *Real World Research: A Resource for Social Scientists and Practitioner-Researchers*. 3rd ed. London: Blackwell Publishing.

Rowley, J. (2014). Designing and using research questionnaires. *Management Research Review*, 37(3), pp.308-330.

Russell, A., Chiu, C. and Korde, T. (2009). Visual representation of construction management data. *Automation in Construction*, 18(8), pp.1045-1062.

Saunders, M. and Tosey, P. (2012b). The Layers of Research Design. *Rapport*, Winter 2012/2013, pp.58-59.

Saunders, M., Lewis, P. and Thornhill, A. (2012a). *Research methods for business students*. 6th ed. Harlow: Pearson.

Schofield, D. (2011). Playing with evidence: Using video games in the courtroom. *Entertainment Computing*, 2(1), pp.47-58.

SCL (Society of Construction Law). (2002). *Delay and Disruption Protocol*. Wantage: Society of Construction Law.

SCL (Society of Construction Law). (2015). *Rider 1: The Society of Construction Law Delay and Disruption Protocol*. Wantage: Society of Construction Law.

Scott, S. (1990). Keeping better site records. *International Journal of Project Management*, 8(4), pp.243-249.

Selbak, J. (1994). Digital litigation: the prejudicial effects of computer-generated animation in the courtroom. *High Technology Law Journal*, 9(2), pp.337-367.

Sharp, L., Cochran, C., Cotton, S., Gray, N. and Gallagher, M. (2006). Enclosing a pen with a postal questionnaire can significantly increase the response rate. *Journal of Clinical Epidemiology*, 59(7), pp.747-754.

Sim, J. (1998). Collecting and analysing qualitative data: issues raised by the focus group. *Journal of Advanced Nursing*, 28(2), pp.345-352.

Stewart, D., Shamdasani, P. and Rook, D. (2007). *Focus Groups: Theory and Practice*. 2nd ed. California: SAGE publications.

Trauner, T., Manginelli, W., Lowe, J., Nagata, M. and Furniss, B. (2009). *Construction delays: Understanding them clearly, analysing them correctly*. 2nd ed. London: Elsevier.

UN (United Nations). (2015). *World Population Prospects: The 2015 Revision – Key Findings and Advance Tables Working Paper No. ESA/P/WP.241*. New York: United Nations Department of Economic and Social Affairs (DESA) Population Division.

Vidogah, W. and Ndekugri, I. (1998). A review of the role of information technology in construction claims management. *Computers in Industry*, 35(1), pp.77-85.

Vinten, G. (1995). Open versus closed questions – an open issue? *Management Decision*, 33(4), pp.27-31.

Warszawski, A. and Navon, R. (1987). Development of a robot for interior finishing works. *Proceedings of the Fourth International Symposium on Robotics and Artificial Intelligence in Building Construction, Haifa, 23-25 June, 1987*. Haifa: Technion, pp.245-258.

Webb, R, Smallwood, J. and Haupt, T. (2004). The potential of 4D CAD as a tool for construction management. *Journal of Construction Research*, 5(1), pp.43-60.

Webster, J. and Watson, R. (2002). Analyzing the Past to Prepare For the Future: Writing a Literature Review. *MIS Quarterly*, 26(2), xiii-xxiii.

Whatley, P. (2014). *The project planning handbook*. Leicester: Troubador.

Wieringa, R. (2014). Empirical research methods for technology validation: Scaling up to practice. *Journal of Systems and Software*, 95, pp.19-31.

Wilks, S. and Gibbs, D. (2015). The winner takes it all. *Control, Collaborate, Construct: why information must be managed*. E-book: Union Square, pp.15-16.

Williams, A. (2003b). How to... write and analyse a questionnaire. *Journal of orthodontics*, 30(3), pp.245-252.

Williams, T., Ackermann, F. and Eden, C. (2003a). Structuring a delay and disruption claim: An application of cause-mapping and system dynamics. *European Journal of Operational Research*, 148(1), pp.192-204.

Wilson, J. (2003). Gantt charts: A centenary appreciation. *European Journal of Operational Research*, 149(2), pp.430-437.

Wolff, B., Knodel, J. and Sittitrai, W. (1993). Focus Groups and Surveys as Complementary Research Methods – A Case Example. *In*: D. Morgan, ed. *Successful Focus Groups: Advancing the State of the Art*. California: SAGE publications, 1993, pp.118-136.

World Economic Forum. (2016). *Shaping the Future of Construction: A Breakthrough in Mindset and Technology (prepared in collaboration with the Boston Consulting Group)*. Switzerland: World Economic Forum.

Wright, I. (2011). Alternative dispute resolution. *In*: V. Ramsey, A. Minogue, J. Baster, and M. O'Reilly, ed. *ICE manual of construction law.* London: Thomas Telford, 2011, pp. 499-519.

Yamín, R. and Harmelink, D. (2001). Comparison of Linear Scheduling Model (LSM) and Critical Path Method (CPM). *Journal of Construction Engineering and Management*, 127(5), pp.374-381.

Yin, R. (2013). Validity and generalization in future case study evaluations. *Evaluation*, 19(3), pp.321-332.

Zelkowitz, M. and Wallace, D. (1998). Experimental models for validating technology. *Computer*, 31(5), pp.23-31.

Zhang, J. and Hu, 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, pp.155-166.

Zhou, Y., Ding, L., Wang, X., Truijens, M. and Luo, H. (2015). Applicability of 4D modelling for resource allocation in mega liquefied natural gas plant construction. *Automation in Construction*, 50, pp.50-63.

APPENDIX A JOURNAL PAPER 1

Gibbs, D., Emmitt, S., Ruikar, K. and Lord, W. (2013). An Investigation into whether Building Information Modelling (BIM) can Assist with Construction Delay Claims. *International Journal of 3-D Information Modeling*, 2(1), pp.45-52.

An Investigation into whether Building Information Modelling (BIM) can Assist with Construction Delay Claims

ABSTRACT

It is probable that a construction project anywhere in the world will encounter some form of delay as a consequence of change. The impact of the delay on a project will vary, but it is likely to have a negative financial outcome. Compensation can be requested by an affected party in the form of a claim; however, issues of liability and quantum can be difficult given the ever increasing complexity of construction work involving numerous differing successive parallel tasks with varying levels of interrelated resources. Experts are often employed to analyse delays based on project records and report their findings to a tribunal. This paper identifies the difficulties associated with the retrieval and representation of information for delay claims and recognises technological opportunities to deal with these challenges. The potential to exploit aspects of BIM to support these possibilities are discussed, concluding that it can assist through the ease of access to coordinated contemporaneous project information and the use of visualisation through multiple dimensions. In order to support this initiative a detailed review of the literature is undertaken which forms part of an Engineering Doctorate.

KEYWORDS

Building Information Model; Claims; Construction; Delay; Disputes; Visualisation.

INTRODUCTION

The construction lifecycle is a complex endeavour which incorporates multiple parties to undertake numerous tasks each with varying levels of interrelated resources. The risks associated with construction projects are high and are not supported by the small profit margins that exist. If nothing was to change on a project it would be completed to the planned cost, quality and time; however, even the best laid plans will deviate. Reports show that a trade-off between these elements is likely, with over a third of projects not being completed to the planned time and cost (Egan, 1998). Organisations cannot financially absorb this difference; therefore, the affected party can claim compensation. In order for a claim to be made for time delays, a delay analysis must be undertaken.

Currently, no research has been undertaken to investigate whether elements of BIM can be exploited to support construction delay claims. To bridge this gap, this paper explores both construction delay and BIM literature. The fundamentals of delay analysis are explained and some of the challenges encountered by analysts are discussed. Potential technological opportunities to mitigate these challenges are identified, and a connection to some of the benefits related to BIM are realised and discussed.

DELAY

The term delay is exhaustively used in the construction industry; however, no standard form of construction contract defines the term due to the comparative nature in which it is used (Pickavance, 2010). For the purpose of this paper, delays are referred to as an unanticipated extension to the overall planned time period and/or the incident which prolongs the duration of an activity without affecting the overall project duration (Bramble, 2000). Therefore, the process of analysing delays can be viewed as the forensic investigation into an issue which has caused a time overrun (Farrow, 2001). This is distinctly different from disruption, a term generally conjoined with delay, which is the loss of efficiency due to low productivity or an interference with progress (Cooke, 2009). The topic of disruption is not considered in this paper; however, both delay and disruption can result in a claim and some of the discussion may be transferable.

Categories of Delay

Subject to the claiming party, different forms of compensation can be requested depending on how the delay is classified. In order to analyse delay, the first step is to decipher responsibility by categorising whether the event is excusable or non-excusable.

Non-excusable delays, also known as culpable delays, contractor delays or inexcusable delays (SCL, 2002), are delays within the contractors control; thus, they assume responsibility for the delay and its impact on the other parties (Bramble, 2000). In contrast, excusable delays, also known as non-culpable delays and employer delays (Cooke, 2009), are delays beyond the control of the contractor which allows them a form of compensation. The compensation available will depend on whether the event is deemed compensable or non-compensable.

Under a non-compensable event the contractor can obtain an extension of time which provides the contractor with an extension to the agreed contract completion date and acts as a mechanism to protect the client’s entitlement to liquidated damages. If the delay event is deemed compensable the contractor can claim loss and expense, but they must prove the damages they have suffered from events not their fault. A combination of both forms of compensation is also possible.

The client can claim compensation in the form of actual damages or liquidated damages. Actual damages are calculated post delay and must be proven, whereas liquidated damages are included in the contract as a pre-estimate of the damages the client will suffer if the project is not completed by the contract date. The contractor is legally obliged to pay the value set in the contract unless they claim excusable delay.

The exact conditions for determining the category of delay will be outlined in the construction contract. However, it is unlikely that there will be a single form of delay on the project which adds to the complexity of categorisation and allocation of responsibility. More probable than not, a construction project will encounter multiple delays which may occur at the same time and/or become intertwined with each other. The challenge given to delay analysts is to categorise and quantify these delays and represent the findings in a suitable manner.

Delay Analysis: The Current Position

In order to claim compensation for delay, the burden of proof is placed with the claimant. If enough evidence is provided in their favour, the burden of proof passes over to the other party (Haidar, 2011).

Unlike criminal proceedings, the standard of proof in civil proceedings is based on an event being more likely than not to have occurred. The ‘balance of probabilities’ principle states that, no matter how small an amount, one side’s claim must prove to be more likely than the other to be successful. The balance can be tipped on the strength of evidence; however, the quantity and quality available will vary between claims and the standard required to shift the balance will depend on the severity of the case. In general, the stronger the evidence the more likely the claim is to be successful, with particular weighting given to contemporaneous records. Records can take numerous forms and include computer-aided project management tools (Haidar, 2011).

Scheduling project management tools are an accepted method to illustrate delay claims as long as they prove reliable (Barry, 2009). The project schedule, which is different from project planning, generates an overall project duration by sequencing all of the activities required to complete the works using mathematical calculations and logic (CIOB, 2011). A critical path can be shown on the schedule which depicts the key activities required to finish the project with the shortest duration. If there is a time slippage on any of these critical activities, the project duration will be extended. The activities not on the critical path can contain float, which is the duration they can be delayed before becoming critical to the overall project duration. If undertaken correctly, the schedule will show how change impacts the project duration.

There are a variety of delay analysis methodologies available which use schedules, with different titles given to the same methodologies. Bubshait (1998) states that there is no universal method for analysing delay; therefore, the selected methodology should be the one which best represents the claim. The SCL

Delay and Disruption Protocol (2002) recommends the following methodologies for analysing delay: 1. As-planned vs as-built; 2. Impacted as-planned; 3. Collapsed as-built; or 4. Time impact analysis. Arditi (2006) comments on the usefulness of each of these concluding that time impact analysis is the most reliable. Despite this, the choice of methodology can be influenced by a variety of factors, most notably, the availability of records (Braimah, 2008).

Delay Claim Challenges

Retrieval of Information

Records are fundamental in analysing and supporting delay claims; however, retrieving the information, if at all it exists, is not always straightforward. Research by the CIOB (2008) showed that 22% of respondents were not aware of delay and compensation related events being recorded. Pickavance (2010) attributes this to the fact that there is no requirement in many standard forms of construction contract to keep records.

Where records are kept throughout the lifecycle of a project they will take a range of forms for a variety of purposes. Consequently, mass amounts of information is stored and communicated on a project (Vidogah, 1998). The most useful records, with respect to delay claims, are progress records and change management records (Pickavance, 2010). It is probable that this information would have been recorded in some form; however, it may not be easily retrieved (Scott, 1990). Accessing documents, particularly paper based items, proves a difficult challenge and can be a costly and laborious process (Vidogah, 1998). Research by Joia (1998) found that consultancy firms spent 8 hours a week retrieving lost or incorrectly stored data. The PIX Protocol (Goodwin, 2004) attributes this to the inherent use of paper on construction projects despite the advanced IT systems most organisations possess.

Visualisation

A delay claim will attempt to demonstrate the claimant's interpretation of what occurred on the project. A report will identify the cause and effect relationship of the damages suffered from the other party's actions (Trauner, 2009). The quality of the report is likely to influence the success of the claim (Liulihong, 2011) and must prove liability, causation and quantum (Williams, 2003).

At present, a delay claim may involve numerous lever arch files containing complex schedules and supporting evidence. Although the various delay analysis methodologies are accepted as a means to show the cause and impact of delay, they can be difficult to understand (Kumaraswamy, 2003). Deciphering the information to allow for an informed judgment to be made can prove a challenging task for the tribunal who may have limited construction and schedule knowledge. These points are emphasised by Arden L.J. in the Hunte v Bottomley case:

> *Many cases of this kind, however, and I am sorry to say that this is one of them, are prepared in a way which makes it very difficult for members of this court when reading the papers in preparation for the appeal hearing, to read the plan, map, diagram or photograph correctly, or to follow fully the submissions of the parties about those documents or the court cannot be certain about what the plan, diagram, map or photograph shows until the appeal is opened and they are fully explained. Those who prepare bundles or skeleton arguments would do well to remember that a plan, map, diagram or photograph which is clear to people who are fully familiar with the case may well not be wholly clear to a judge coming to the case for the first time.*

To combat these problems, the courts are moving closer to e-disclosure and the use of screens as a method of communicating a case. Therefore, the potential to use modern technology to represent delay as a response to change is possible.

TECHNOLOGICAL OPPORTUNITIES

Compared to the phases in the lifecycle of a construction project, construction claims have benefited the least from bespoke developments in information technology. Instead, they work off systems built for other purposes which can limit the output desired from the software (Vidogah, 1998).

Retrieval

It is widely stated in the literature, and accepted in the industry, that a central, electronic, hub should be used to store all project information. Such a document management system can house contemporary records which can be used to monitor and control the project.

A reason why disputes occur is due to a difference of information (Pickavance, 2010). A centralised, electronic, hub ensures that the most up to date information is readily accessible to all parties involved on the project. In the event of a delay claim, all of the project information can be understood, accessed, sorted, filtered and reported at a faster rate than paper or unmanaged electronic information (CIOB, 2011). A variety of organisations, external to the construction project, offer these services using web-based platforms (Chassiakos, 2008). If these systems are implemented and followed correctly the claim is less likely to be disputed (Vidogah, 1998). Needless to say, the system used is only as good as the information put in and an adequate record keeping system must be adhered to (CIOB, 2011).

If the information is readily available to undertake a delay analysis and act as supporting evidence, technological developments can further assist with visualising the claim.

Visualisation

Pickavance (2010) identifies that there are three different ways in which delay evidence can be presented: 1. Orally; 2. By hand documentation; 3. By computerised presentation of electronic data. Extending the use of computerised presentation past construction schedules, the potential to use computer generated visualisations to assist with the communication of delay claims are discussed.

The use of visualisations to improve communication is predominantly used in architectural design but its benefits can be realised throughout the project lifecycle (Bouchlaghem, 2005). Its opportunity to assist with legal proceedings is expected to rise given that courts are becoming increasingly technologically sophisticated (Narayanan, 2001) and, if used correctly, they may be suitable in adjudication and some arbitrations (Pickavance, 2010). Pickavance (2007) acknowledges the possibility of using forensic animations to resolve disruption claims but recognises that their value as evidence will vary depending on how they are used and the supporting information behind their generation (Schofield, 2005).

Outside of the construction industry, visualisations have been used in the courtroom. These include the 1998 UK inquiry into the events of Bloody Sunday in Londonderry 1972 and the 2001 Carla Terry murder case in Connecticut. The latter identifies the following requirements for visualisations to be accepted as supporting evidence in the US courts:

- The equipment used is standard in the field and is shown to be in good working order;
- Qualified operators, procedures and reliable software are employed to produce the output;
- The equipment was operated correctly;
- The exhibit is identified as the output produced.

An array of software providers offer services in which models can be designed in 3D; however, this cannot be directly linked to the delay analysis information available, thus, the standalone model may be insufficient. A solution to combine the two elements together is found in BIM.

A SOLUTION: BIM?

BIM is not a new idea (Napier, 2009), but has recently gained widespread interest as a result of the UK governments' mandate to use it on public sector projects by 2016 (Cabinet Office, 2011). Despite the increase in awareness, research by the National Building Specification (NBS, 2012) discovered that 21% of respondents were uncertain as to what BIM was despite being defined in their 2011 report as "a rich information model, consisting of potentially multiple data sources, elements of which can be shared across all stakeholders and be maintained across the life of a building from inception to recycling (cradle to cradle). The information model can include contract and specification properties, personnel, programming, quantities, cost, spaces and geometry" (NBS, 2011).

The potential opportunities and challenges associated with BIM are widely discussed in the literature and can be realised in all aspects of the construction lifecycle (Eastman, 2011). If used correctly, it is suggested that fewer projects will result in disputes due to improved collaboration. This may be true as little documentation on BIM related disputes exists, although it could be argued that this is attributed to the limited number of BIM projects undertaken.

From identifying the technological opportunities available to enhance delay analysis, opportunities are recognised in BIM for both projects which used it through its lifecycle, and for those which have not used it at all.

Coordinated Contemporaneous Project Information

BIM offers a way of coordinating all project information throughout its lifecycle. If a project used BIM from inception and followed recommended record keeping procedures, all project information would be stored in a central database and linked to a 3D model. Through the potential of mobile computing on construction projects, the recording of high value contemporaneous records may increase.

Furthermore, the disparate information which traditionally exists on construction projects is removed as all information can be coordinated. This is supported by developments from buildingSMART to assist interoperability of software through Industry Foundation Classes (IFC). With a common language between software packages, information can easily be updated and the impact of change realised through the linked information. The representation of this information can be further enhanced through the visual capabilities of BIM.

Visualisation through Multiple Dimensions

BIM moves away from traditional 2D design and represents the project in 3D using objects which respond to each other’s properties and recognise space. Through the collaborative working processes and interoperable nature of information exchange, multiple dimensions (nD) open up as a result of the coordinated information (Tao-Chiu, 2005).

With respect to delay claims, the fourth dimension (time) and fifth dimension (cost) appear to offer assistance; however, they are currently only considered as support for project control (Hartmann, 2012). Current project scheduling software links time and cost but it is not always easy to understand the cause and effect of change. The innovation is to use the multiple dimensions by linking the information generated in the delay analysis to an nD representation of the project. This information can then be passed to the tribunal to support the delay claim subject to legal requirements.

In an event where BIM, or 3D modelling, were not used on a project, and it may prove too time consuming to model the project, laser scanning could be used to quickly produce a 3D model using point clouds (Tang, 2010). The information produced by the delay analyst could then be linked to a visual representation of the project to better represent the cause and effect of the delay.

CONCLUSION

The paper presents a review of the literature to show the current position of delay claims. It recognises two challenges that delay analysts encounter as the retrieval of information and the clear representation of the analysis. Technological opportunities in the form of document management systems and computerised visualisations are identified as ways to combat these challenges. BIM is recognised as a platform which can support these attributes in one system through coordinated project information and nD modelling. Its use can be extended to projects not using 3D modelling through the advancements of laser scanning.

In order to progress this initiative, the legal aspects of BIM need to be explored. Issues on ownership and intellectual property are not clear due to the lack of rules and protocols set out. The ability to use the information in the model as evidence needs to be investigated in relation to e-disclosure. If feasible, or whether paper documents must be presented, a clear progression in research is to undertake a case study to determine the opportunities and challenges of exploiting aspects of BIM to assist with construction delay claims. This will continue to be addressed through Engineering Doctorate research.

REFERENCES

Arditi, D., & Pattanakitchamroon, T. (2006). Selecting a delay analysis method in resolving construction claims. *International Journal of Project Management*, *24*, 145–155. doi:10.1016/j.ijproman.2005.08.005.

Barry, D. (2009). *Beware of the dark arts! Delay analysis and the problems with reliance on technology*. Society of Construction Law.

Bouchlaghem, D., Shang, H., Whyte, J., & Ganah, A. (2005). Visualisation in architecture, engineering and construction (AEC). *Automation in Construction*, *14*, 287–295. doi:10.1016/j.autcon.2004.08.012.

Braimah, N., & Ndekugri, I. (2008). Factors influencing the selection of delay analysis methodologies. *International Journal of Project Management*, *26*, 789–799. doi:10.1016/j.ijproman.2007.09.001.

Bramble, B., & Callahan, M. (2000). *Construction delay claims* (3rd ed.). Gaithersburg, MD: Aspen Law and Business.

Bubshait, A., & Cunningham, M. (1998). Comparison of delay analysis methodologies. *Journal of Construction Engineering and Management*, 315–322. doi:10.1061/(ASCE)0733-9364(1998)124:4(315).

Cabinet Office. (2011). Government construction strategy. May 2011.

Chassiakos, A., & Sakellaropoulos, S. (2008). A web-based system for managing construction information. *Advances in Engineering Software*, *39*, 865–876. doi:10.1016/j.advengsoft.2008.05.006.

CIOB. (2008). *Managing the risk of delayed completion in the 21st century*. The Chartered Institute of Building.

CIOB. (2011). *Guide to good practice in the management of time in complex projects*. Hoboken, NJ: John Wiley-Blackwell.

Cooke, B., & Williams, P. (2009). *Construction planning, programming and control* (3rd ed.). West Sussex, UK: Wiley-Blackwell.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors*. Hoboken, NJ: John Wiley & Sons, Inc..

Egan, J. (1998). *Rethinking construction: Report of the construction task force on the scope for improving the quality and the efficiency of UK construction*. Department of the Environment, Transport and Regions.

Farrow, T. (2001). *Delay analysis – methodology and mythology*. Society of Construction Law.

Goodwin, P. (2004). *The PIX protocol: A risk reduction tool for construction projects*. Society of Construction Law.

Haidar, A., & Barnes, P. (2011). *Delay and disruption claims in construction: A practical approach*. London, UK: ICE publishing. doi:10.1680/ddcc.57050.

Hartmann, T., Meerveld, H., Vossebeld, N., & Adriaanse, A. (in press). Aligning building information model tools and construction management methods. [Article in Press]. *Automation in Construction*.

Joia, L. (1998). Large-scale reengineering in project documentation and workflow at engineering consultancy companies. *International Journal of Information Management*, *18*(3), 215–224. doi:10.1016/S0268-4012(98)00006-1.

Kumaraswamy, M., & Yogeswaran, K. (2003). Substantiation and assessment of claims for extensions of time. *International Journal of Project Management*, *21*, 27–38. doi:10.1016/S0263-7863(01)00052-7.

Liulihong. (2011). Study on the present condition of construction claim and countermeasure. *Energy Procedia, 13*, 2837-2841.

Napier, B., Connolly, K., & Jernigan, F. (2009). *Building information modeling – A report on the current state of BIM technologies and recommendations for implementation*. The State of Wisconsin Department of Administration Division of State Facilities.

Narayanan, A., & Hibbin, S. (2001). Can animations be safely used in court? *Artificial Intelligence and Law*, *9*, 271–293. doi:10.1023/A:1013866317222.

NBS. (2011). *Building information modelling.*

NBS. (2012). *National BIM report*.

Pickavance, K. (2007). *Using advanced forensic animations to resolve complex disruption claims*. Society of Construction Law.

Pickavance, K. (2010). *Delay and Disruption in Construction Contracts* (4th ed.). London, England: Sweet & Maxwell.

Schofield, D., Hussin, N., & Shalaby, M. (2005). A methodology for the evidential analysis of computer-generated animation (CGA). In *Proceedings of the Ninth International Conference on Information Visualisation (IV'05)*.

SCL. (2002). *Delay and disruption protocol*. Society of Construction Law.

Scott, S. (1990). Keeping better site records. *Project Management*, *8*(4), 243–249. doi:10.1016/0263-7863(90)90033-8.

Tang, P., Huber, D., Akinci, B., Lipman, R., & Lytle, A. (2010). Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques. *Automation in Construction*, *19*, 829–843. doi:10.1016/j. autcon.2010.06.007.

Tao-Chiu, K., Kam-Din, A., & Kwan-Wah, F. (2005). The utilisation of building information modelling in nD modelling: A study of data interfacing and adoption barriers. *ITcon, 10*.

Trauner, T., Manginelli, W., Lowe, J., Nagata, M., & Furniss, B. (2009). *Construction delays: Understanding them clearly, analysing them correctly* (2nd ed.). London, UK: Elsevier.

Vidogah, W., & Ndekugri, I. (1998). A review of the role of information technology in construction claims management. *Computers in Industry*, *35*, 77–85. doi:10.1016/S0166-3615(97)00085-7.

Williams, T., Ackermann, F., & Eden, C. (2003). Structuring a delay and disruption claim: An application of cause-mapping and system dynamics. *European Journal of Operational Research*, *148*, 192–204. doi:10.1016/S0377-2217(02)00372-7.

APPENDIX B JOURNAL PAPER 2

Gibbs, D., Lord, W., Emmitt, S. and Ruikar, K. (2015). Building Information Modelling. *Construction Law Journal*, 31(3), pp.167-179.

Building Information Modelling

INTRODUCTION

Since the fourth edition of Delay and Disruption in Construction Contracts[1] was published there has been a significant increase in the recognition and uptake of Building Information Modelling (BIM) on construction projects around the world. As BIM continues to develop, the understanding of the subject and the speed of adoption varies between different countries.[2] As a consequence, this has led to "BIM" meaning different things, to different people, across the globe.[3] To offer some clarity on the subject and update the BIM knowledge found in Delay and Disruption in Construction Contracts, a detailed review of the literature associated with BIM is presented and is used to determine the potential effect BIM might have on construction claims and disputes.

KEYWORDS

Computer modelling; Construction disputes; Construction projects.

WHAT IS BIM?

The acronym BIM has caused confusion in the construction industry. In the published literature, there is inconsistency of the word represented by the letter "M", with terms such as: Building Information Model, Building Information Modelling and Building Information Management emerging. In some instances, the acronym has extended to BIM(M) (Building Information Modelling and Management), which also suffers from the dual spelling of "Modeling". Further confusion is contributed by the word "Building", which suggests that BIM is specifically for buildings. However, it is widely accepted that BIM is applicable to non-building works, such as infrastructure projects.[4]

Even if the same words are used to form the acronym, a universally accepted definition of BIM does not exist.[5] As a result, a great deal of ambiguity exists.[6]

Attempting to understand this ambiguity, there appears to be a difference between theory (BIM as a process) and practice (BIM as a technology). The paragraphs concerning BIM in the fourth edition (at paras 13–067 to 13–069 inclusive) focus upon BIM as an "intelligent" 3D model, which aligns the text to the term Building Information Model (a technology). Whilst the benefits of intelligent 3D models discussed in those paragraphs still remain apposite, it can also be argued that focus on the model and technology is a common misconception of BIM. Instead, the more widely understood terminology for BIM is Building Information Modelling, which can be defined as

"a rich information model, consisting of potentially multiple data sources, elements of which can be shared across all stakeholders and be maintained across the life of a building from inception to recycling (cradle to cradle)".[7]

What's involved and how does it differ from "conventional" practice?

Regardless of the words used to form the acronym and its precise definition, BIM (in a broad sense) is becoming growingly accepted as a process of generating and sharing information (predominantly electronic) throughout the lifecycle of a built asset. This requires documentation, non-graphical data and graphical model(s)[8] to be created, managed and shared in a structured manner in order to ensure that the correct information is given to the appropriate people, at the appropriate time. These outputs are to be stored in a Common Data Environment (CDE) for the lifecycle of the built asset, thereby allowing one point of access for all data and information related to the asset.

In order to achieve this, collaboration between all project team members is required, which is underpinned by tools and technology.[9] On the surface, this may appear not to be anything new and could arguably be characterised as “best practice”; however, where BIM differs from other approaches is in the development and use of the “information model”.[10]

The information model lies at the heart of BIM. Here, non-graphical data and documentation can be linked to, or embedded and generated from, a 3D virtual representation of the works, which is to be produced using object-based parametric modelling software. This software advances from “traditional” Computer-Aided Design (CAD) based lines and places objects with rules and parameters, which determine both geometric and non-geometric properties and features.[11] The relationships and constraints between objects ensures realistic connections as between elements and, through synchronisation, a change to an object in one view will automatically update all other views and linked information.

The benefits of synchronised information can be expanded to multiple dimensions, which include 4D (time), 5D (cost), 6D (FM)[12] and beyond (nD).[13] If the dimensions or individual models are correctly synchronised, a change in any model view or dimension will instantly change all of the linked information and could be used to report the most up-to-date information for the asset.

BIM maturity

Given the various capabilities of BIM, it is not enough for organisations, or projects, to simply say “we do BIM”. In an attempt to take the ambiguity out of the term and to make specification easier, the UK has created a BIM “maturity wedge” to support their requirement of “fully collaborative 3D BIM (with project and asset information, documentation and data being electronic) as a minimum by 2016”[14] for all centrally-procured government projects in the UK. This target level of BIM is commonly referred to as “Level 2” and the various levels of maturity can be defined as.

- **Level 0:**
  Poorly managed CAD (predominantly 2D), which is exchanged using paper, or electronic paper.
- **Level 1:**
  Managed 2D and 3D CAD, with a CDE[15] for electronic information exchange, which is the level at which the majority of the UK industry is believed to be operating.
- **Level 2:**
  Managed 3D models produced using parametric modelling software. Each project team member develops an information model, which is brought together by a coordinator in order to produce a “Federated”[16] model. Documentation, graphical and non-graphical data is embedded, or linked into the model within a CDE. This can be furthered to include multiple dimensions.
- **Level 3 and beyond:**
  Although not fully developed, “Level 3” will attempt to address: open data standards; new contracts; improved culture; training; and, industry growth.[17]

These “Levels” are distinctly different from the multiple dimensions (nD) available. It is to be anticipated that organisations will contend that they are operating at a certain level of BIM but this “Level” might well relate to a particular project and may not be adopted company projects.

WHAT IS ARGUABLY NOT BIM?

In order to provide some additional clarity with regard to what BIM is and to try to dispel certain of the inconsistent and conflicting information which has been published to date, it could be argued that BIM is not the following:

- **Just 3D modelling—**
  it is not CAD; BIM requires virtual models to be created using parametric modelling software and is not merely high rendered images, used solely for tendering purposes (“Hollywood BIM”)[18];

- **Just technology/software—**
  although technology and software form a significant part of BIM, BIM is generally accepted to be a process of working and, it follows that, you cannot simply "buy it off the shelf"; or
- **Working in isolation ("Lonely BIM")**[19]**—**
  BIM inevitably requires a collaborative approach as between all project team members and is not only for a small group of users involved in the project. Neither is it enough for a project team member to work in splendid isolation and not share their documentation, non-graphical data and graphical models.

PERCEIVED BENEFITS OF WORKING IN A BIM ENVIRONMENT

The benefits of BIM increase as one progresses through the various levels of maturity. Whilst some of the benefits associated with intelligent 3D modelling[20] do indeed overlap with certain of the benefits of working in a BIM environment, the benefits associated with BIM as a process must also be acknowledged.

These benefits are well recorded in the literature[21] and can be broadly categorised as the following:

- better collaboration and improved team relationships;
- ease of access to project/asset information;
- easier analysis of the ongoing project/asset;
- concepts are easier to realise and alternatives easier to formulate;
- improved workflow cycle time and reduce waste (double working);
- reduced lifecycle cost and schedule growth, as well as improved certainty; and
- more sustainable construction and green performance of the asset.

Whilst these particular benefits are not always well quantified, it is believed that benefits can be realised by each project team member[22] which, in turn, will benefit the overall project/asset.

PERCEIVED BARRIERS AGAINST BIM ADOPTION

Moving away from any conventional practice will usually engender caution and create some form of resistance. Whilst the benefits of BIM are widely acknowledged, countering this are perceived challenges, which can act as barriers to BIM adoption. The perceived barriers identified below are grouped into four categories, which have a certain degree of overlap and which are specific to "Level 2" BIM. More advanced "Levels" will probably produce additional barriers against adoption.

Collaboration

BIM is a collaborative way of working[23]; but collaboration is more than information sharing. Collaboration involves a collaborative culture; external and internal trust and mutuality; technology and tools; process integration; and, strategic planning.[24] BIM therefore requires a shift from the "silo working" found on many construction projects[25] and a move away from entrenched resistance to the use of new tools and technologies. This could well prove to be challenging since the nature of construction involves short term, interdependent, multi-party teams, with differing organisational goals. This has resulted in certain individuals and project teams becoming orientated towards a conflict-based business.[26] Sharing power in order to support a collaborative environment may, therefore, be extremely difficult for some "team members" to accept and could well generate resistance from individuals, organisations and as a whole industry.[27]

Furthermore, there is a perceived lack of confidence in technology. BIM requires the use of various different pieces of software so in order to obtain maximum value in a "Level 2" BIM environment, it must be possible for technologies to seamlessly interact with one another. It is estimated that inadequate interoperability costs the capital facilities industry in the US approximately $15.8 billion per year, in addition to significant inefficiency and lost opportunity costs.[28] Whilst attempts have been made to resolve issues of interoperability, particularly as between different parametric modelling software packages, a lack of confidence still remains within the construction industry as to whether the original file is presented as intended outside of its native file format.[29] This is a particular problem when a federated model is produced using differing software packages.

Legal, contractual and insurance issues

It can be argued that "Level 2" BIM alters relationships and blurs the lines of roles and responsibility of project team members. This has already generated considerable uncertainty regarding liability, insurance and ownership.[30] The change from conventional construction to a BIM environment opens up questions from both promoters and participants.[31] Common questions in this regard include the following:

- Who owns the federated model?
- Who is responsible for creating, analysing and updating the federated model?
- When will information be delivered and how much can it be relied upon?
- What is the priority of documents?
- Which is the most suitable construction contract and what amendments are required thereto if any?
- Which form of insurance is appropriate and what is covered thereby?

Use and management of information

The manner in which information is generated and utilised during the design, construction and maintenance of a built asset changes on BIM projects. Within a "Level 2" environment, paper documentation is limited and, where possible, information should always be provided in electronic format. This allows information to move and be accessed quicker than when conventional methods are being used. Like paper-based information, the most up-to-date electronic information requires to be stored and made available so that the appropriate project team member can retrieve and use this as required.

Although there has been a gradual move towards electronic information in the construction industry, a preference for paper documentation,[32] particularly for site management,[33] remains. When electronic information is used, it is not always well managed, which can prove particularly challenging for individuals to retrieve the information for which they are looking.[34] A "Level 2" environment might well exacerbate this problem because of the mass of data which can be created and the reliance upon the contribution of information from other project team members. No longer can the release of information be governed by what is deemed "reasonable" and the greater transparency of information brings about the responsibility to warn other project team members of potential changes.[35]

Furthermore, the manner in which information is communicated changes within a "Level 2" environment. Trust must be given to individual(s) managing the project information and, for the majority of the construction industry, parametric models are a new method of information exchange. Organisations are, therefore, required to understand how the information model can be used to convey and retrieve information.

Investment

Although BIM is more than software, hardware and training, these aspects form a fundamental part of the process. The requirement for each of these is different to that of conventional construction projects and will therefore require investment.

The purchasing, maintenance and upgrading of software which has been developed to support "Level 2" tends to be more expensive than conventional CAD packages.[36] A certain level of computing power, which may not be found on the standard computers of most organisations, is required in order to support these software requirements. Hardware upgrades may therefore also be required. Training will be required in order to facilitate understanding of the new software and hardware, as well as the change in the process of generation, sharing and retrieval of information. This can be a direct and indirect cost for an organisation in terms of both time and money.

OVERCOMING THE BARRIERS

In order to overcome the perceived barriers associated with "Level 2" adoption, BIM specific information and guidance has been published which, taken together with recommended basic principles,[37] may be considered as "current best practice". In addition to this, case studies have been undertaken in an attempt to demonstrate the practical application of BIM.

Key documents

The UK government is fully committed to BIM and attempts are being made to position the UK as a world leader in the take-up of BIM.[38] It is suggested that in order to facilitate "Level 2" BIM adoption some of the documents that need to be considered include:

1. BIM Protocol[39];
2. BS 1192:2007;
3. PAS 1192-2: 2013;
4. PAS 1192-3: 2014;
5. BS 1192-4: 2014[40];
6. PAS 1192-5[41];
7. BIM Tool Kit[42]; and
8. Government Soft Landings,

Case studies

A plethora of promotional information has been released by various organisations and projects, asserting that they have "adopted" BIM. However, it could well be argued that the majority of these projects are not operating in a true "Level 2" BIM environment. Instead, many of these projects share certain of the characteristics of "what BIM isn't". This is not to say that the information contained within these reports should be disregarded, since some of it is extremely valuable and lays the foundations by which to achieve "Level 2" compliance; however, caution should always be observed when drawing comparisons with a true "Level 2" BIM environment.

Understandably, the move of the industry towards "Level 2" BIM will be a gradual one and, in some cases, a natural process. The United Kingdom's government recognises this and has undertaken a trial "Level 2" BIM project.

Cookham Wood

The Ministry of Justice's Cookham Wood youth offender's development is the first of all the UK government's projects to test the application of BIM "Level 2". Alongside this initiative, the project trialled Two Stage Open Book tendering,[43] which compliments BIM by seeking to achieve efficiency gains through the early appointment of a full project team.[44]

The project was operated under the PPC2000 form of contract. No amendment to the contract was made in respect of BIM, nor was a BIM protocol used. This alternative approach of establishing a BIM environment was made possible by creating a set of mutual intellectual property licences, linking a series of deadlines to the contract and using standard contract provisions under PPC2000's multi-party structure.[45] The successful implementation of this is thought to have been achieved by having a client who was fully committed and informed about BIM.

Despite bad weather, the project (which was valued at £20 million) reported benefits of improved cost and programme certainty, increased innovation and reduced likely operating costs of the built asset.[46] It is reported that an overall saving of 20 per cent was achieved on the project, most notably through collaborative working, which achieved best value solutions through client-contractor review of work packages and a reduction in the construction programme by six weeks. BIM also assisted with the understanding of clients, early design coordination and change management, together with maintenance benefits.

However, it is reported that the key lesson learnt from the project was the value of "early contractor involvement". Therefore, it could also be argued that some of the benefits associated with the project could have been realised if BIM had not been adopted. As a consequence, the trial project alone has not given some individuals the confidence they require to adopt "Level 2" BIM on their projects.

Future projects

Other trial BIM projects are now set to be undertaken and if the perceived benefits of "Level 2" BIM are realised and reported, alongside a description of the management of challenges which were overcome, it is likely to give organisations more confidence to adopt BIM.

STANDARD FORMS OF CONTRACT

It is not common for BIM to be referenced or adopted within standard forms of contract[47] but it has been suggested that little change is required to standard forms of contract in order to facilitate "Level 2" BIM adoption.[48]

In order to encourage and facilitate the incorporation of "Level 2" BIM into NEC3 contracts and to reduce the need for bespoke amendments thereto, NEC3 has published "How to use BIM with NEC3 Contracts"[49] which focuses upon the creation of "the model". This guide recommends that technical requirements (such as information production and timescale) are to be inserted into the Work Information/Subcontract Works Information, or Scope and rights and liabilities of the parties are to be inserted into the contract using "Z" clauses. The guide also promotes the use of a BIM protocol and proffers advice upon incorporating the CIC BIM protocol into the various NEC3 contract forms. These recommendations are appropriate for the suite of NEC3 contracts except for, in certain instances, the short versions of contract and the Term Service Contract. However, it can be argued that the NEC3 guidance does very little except to say elements of the CIC BIM Protocol should be incorporated but taking note on the different styles of wording in the NEC3 and Protocol.

The JCT has also published a Public Sector Supplement, which suggests steps and modifications to be made when design work and information exchange is governed by a BIM protocol.[50] This covers a variety of main contracts and sub-contracts, including the Constructing Excellence Contract, which is one of the standard forms of contract encouraging collaborative working. The BIM protocol can be included in the Preliminaries/Employer's Requirements, or other contract documents, and contains advice on incorporation of the protocol into the contract and points to consider when doing so are published.[51] However, the CIC BIM Protocol makes it clear that it should take priority over the contract but, as it is included in the Employer's Requirements under JCT, particular note should be made to Clause 1.3 of the JCT DB11 contract which says "nothing sustained in the Employer's Requirements ... shall override of modify the Agreement or these conditions".

Despite the popularity of the NEC3 and JCT suites of contract on conventional construction projects, PPC2000 was the contract of choice for the UK government's "Level 2" BIM trial projects. As a multi-party contract, PPC2000 was favoured, because it governs the duration of the procurement process and promotes collaboration by bringing in key project participants at the design phase of the project and could well be operated without the need for a BIM protocol.[52]

In addition to these established standard forms of contract, the recently released CIOB Complex Projects Contract 2013 (CPC 2013) is the first standard form of construction contract to include BIM provisions within its clauses and appendices. Like BIM, CPC 2013 was born out of an attempt to address the inefficiencies of the construction industry. As a consequence, BIM and CPC 2013 complement each other on ideas, such as: transparent electronic information; increased certainty through high value project information; front end investment in order to reduce the likelihood of future problems and high levels of collaboration.[53]

Further integration of BIM into standard forms of construction contract is likely, such as the inclusion of BIM into the re-launch of the Infrastructure Conditions of Contract (ICC). However, it must be remembered that all of these contracts are perceived to be suitable for "Level 2" BIM and anything more developed than the requirements of this level may require more sophisticated contractual arrangements.

WHAT DOES BIM MEAN FOR CLAIMS AND DISPUTES?

It is envisaged that the benefits of working in a "Level 2" BIM environment will "include fewer delays and disputes within the team, better management of project risk and better understanding of where costs are being incurred".[54]

Claims are not an indication of failure. They can be viewed as a natural part of any construction project because change is inevitable on any project; therefore, claims are still likely to occur on BIM projects. If a change has a negative impact upon a party and it is not their contractual risk to bear, they are entitled to submit a claim in order to return them to the position which they would otherwise have been in if the change had not occurred. However, if the claim is rejected, it can develop into a dispute, which can have a negative impact upon all of the parties and the wider industry.[55] It is, therefore, thought that the collaborative nature of BIM should reduce the number of claims which develop into disputes.

If synchronisation as between different dimensions is achieved and best practice is followed, when claims arise then the consequential effect of the change on the project can be instantly reviewed. However, creating and updating a system which accurately reflects the effect of a change on a complex project across multiple dimensions is a feat. If such an approach is used, a detailed description of the links and rules used between different dimensions is required and needs to be vigorously checked in order to ensure that the output is correct.

By reason of the complexity of such an interrelated system, there is likely to be a lack of confidence in the output, especially whilst "Level 2" BIM and the supporting software remain unfamiliar. Instead, aspects of BIM could be used to assist with the retrieval and communication of information in order to support a claim, or a dispute.[56]

Retrieval of information

Conventionally, construction project records are not usually well-kept,[57] which can make the proof of the cause and effect of a change event upon a project difficult, especially for retrospective analysis. Within a BIM environment, whenever the process is undertaken as intended, a certain level of information should be generated at different stages of the project in order to allow for its successful management. The process of contemporaneous record keeping is facilitated by certain of the software packages, which have been developed in order to support BIM and the possibility of using handheld devices to create live data.[58]

If project information is stored electronically, in a CDE and in a structured way, the process of finding information is much easier because it can be searched, sorted and filtered. This is not too dissimilar to recommended practice, which is undertaken on some projects which have not adopted BIM; however, where BIM differs from this best practice, is in the use of the virtual model. If project information is embedded in or linked to the virtual model, it is possible to use the model as a central reference point in order to find all relevant information. This can create a clear audit trail and is particularly useful when trying to find information relating to a certain aspect of work.

Communication of information

Construction claims and disputes sometimes involve the presentation of information to individuals who have not been directly involved in the project and may have limited practical construction experience. Virtual models can be useful so as visually to support a written narrative in order to help provide better understanding of what occurred on a project.

Not all construction projects use 3D models, but they are sometimes developed for the sole purpose of assisting the understanding of contentious issues. However, this can be a costly and time consuming process and the visualisations are not always as effective as they could be. This has given rise to recommendations regarding the creation of computer-generated exhibits in order to support construction claims.[59] Given that virtual models are required on all "Level 2" BIM projects, it is therefore likely that there will be an increase in their use in order to support construction claims and disputes. However, direct access to the federated model may be restricted for these purposes, so organisations may have to adapt their individual information model to support their claim or dispute.

CASE LAW

There is very little published information regarding the impact of BIM on disputes. This may be attributed to the limited case law on BIM, which could well be inferred to mean that disputes are less likely upon BIM projects, or it could indicate that only a small number of BIM projects have been undertaken.

The one reported BIM dispute was settled out of court, leaving its details limited. What is known is that the dispute occurred upon the installation of a mechanical, electrical and plumbing system for a life-science building in America. Parametric modelling software was used to create an intricate design; however, a sequencing programme was not created or communicated and resulted in the contractor running out of space to install all of the works.[60] However, this could have occurred on a conventional project so it could be argued that this is not a BIM specific dispute.

THE FUTURE OF CLAIMS AND DISPUTES

BIM is seen by some as a panacea for the problems in the construction industry. Whilst BIM may go some way to resolve common issues which result in claims and disputes (such as on-site clashes between different work packages), it will not be possible to resolve all of the problems. There could also be a shift to other forms of claims, such as information exchange requirements,[61] or inadequate coordination and checking of the federated models.

Furthermore, the same people will still be working in the industry, performing the self-same tasks. If best practice, like the keeping of adequate site records to manage a construction project, is not undertaken by organisations on conventional construction projects, it is unlikely that they will be undertaken in a BIM environment. Those who already follow best practice are therefore likely to embrace and gain the benefits of BIM and, hopefully, avoid disputes. Yet, those who do not follow recommended best practice are likely to be exposed by BIM.

Claims will therefore still form a part of BIM projects, but it is hoped that the process of working involved in a "Level 2" BIM environment will help to reduce the likelihood and severity of these developing into disputes. When disputes do occur, BIM will probably rely upon expert evidence. The collaborative environment may well result in the use of "hot-tubbing"[62] and in the future, could advance the construction dispute resolution system through the addition of new legal documents.[63]

REFERENCES

[1] K. Pickavance, *Delay and Disruption in Construction Contracts*, 4th edn, (London: Sweet & Maxwell, 2010).

[2] McGraw Hill, "The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation with Building Information Modeling". SmartMarket Report, 2014.

[3] NBS, "NBS International BIM Report 2013", 2014.

[4] McGraw Hill, "The Business Value of BIM for Infrastructure: Addressing America's Infrastructure Challenges with Collaboration and Technology". SmartMarket Report, 2012; O. Teall, "Building Information Modelling in the Highways Sector: Major Projects of the Future", 2014; *ICE Management, Procurement and Law*, 167(MP3), 127–133; F. Blanco and H. Chen, "The Implementation of Building Information Modelling in the United Kingdom by the Transport Industry", 2014; (2014) 138 *Procedia—Social and Behavioural Sciences* 210–520.

[5] NBS, "Building Information Modelling Report March 2011", 2011.

[6] B. Abbasnejad, and H. Moud, "BIM and Basic Challenges Associated with its Definitions, Interpretations and Expectations", (2013) 3(2) *International Journal of Engineering Research and Applications* (IJERA) 287–294; D. Zuppa, R. Issa and P. Suermann, "BIM's Impact on the Success Measure of Construction Projects", (2009) *Computing in Civil Engineering* 503–512.

[7] NBS, "Building Information Modelling Report March 2011", 2011.

[8] BSI, PAS1192-2, "Specification for Information Management for the Capital/Delivery Phase of Construction Projects using Building Information Modelling", 2013.

[9] BD, “Investing in BIM: A Guide for Architects”, 2014.

[10] “The information model comprises three constitute parts: Documentation, non-graphical information and graphical information.” BSI, PAS1192-2, “Specification for Information Management for the Capital/Delivery Phase of Construction Projects using Building Information Modelling”, 2013.

[11] C. Eastman, P. Teicholz, R. Sacks, and K. Liston, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, 2nd edn (New Jersey: John Wiley and Sons, 2011).

[12] RIBA, *BIM Overlay to the RIBA Outline Plan of Work*, (London: RIBA Publishing, 2012).

[13] T. Tse, K. Wong and K. Wong, “The utilisation of Building Information Modelling in nD modelling: A study of data interfacing and adoption barriers”, (2005) 10 *Itcon* 85–100; L. Ding, Y. Zhou and B. Akinci, “Building Information Modelling (BIM) application framework: The process of expanding form 3D to computable nD”, (2014) 46 *Automation in Construction* 82–93.

[14] Cabinet Office, “Government Construction Strategy”, May 2011.

[15] A CDE is a “single source of information for any given project, or asset, used to collect, manage and disseminate all relevant approved files, documents and data for multi-disciplinary teams in a managed process”, BSI, PAS 1192-3, “Specification for information management for the operational phase of assets using building information modelling”, 2014.

[16] CIC, “Building Information Model (BIM) Protocol”, Clause 1.1.3: A model consisting of connected but distinct individual Models, 2013.

[17] HM Government, 2015. Digital Built Britain: Level 3 Building Information Modelling—Strategic Plan.

[18] S. Kia, “Review of Building Information Modeling (BIM) Software Packages Based on Assets Management”, Amirkabir University of Technology, 2013.

[19] M. Das, J. Cheng and S. Kumar, “BIMCloud: A Distributed Cloud-based Social BIM Framework for Project Collaboration”, in R. Issa and I. Flood (eds), *Computing in Civil and Building Engineering* (American Society of Civil Engineers: 2014), pp.41–8; McGraw Hill, “The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007–2012)”, SmartMarket Report, 2012.

[20] Pickavance, *Delay and Disruption in Construction Contracts* (2010), para.13-068.

[21] BD, “Investing in BIM: A Guide for Architects”, 2014; McGraw Hill, “The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation with Building Information Modeling”, SmartMarket Report, 2014.

[22] Eastman, Teicholz, Sacks and Liston, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, 2nd edn, (2011).

[23] HM Government, “Building Information Modelling—Industrial strategy: Government and Industry in Partnership”, 2012.

[24] M. Barratt, “Understanding the meaning of collaboration in the supply chain”, (2004) 9(1) *Supply Chain Management: An International Journal* 30–42.

[25] Latham, M., 1994. Constructing the Team: Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry: The Final Report. *H.M.S.O.*; Egan, J., 1998. Rethinking Construction: report of the construction task force on the scope for improving the quality and the efficiency of UK construction. *Department of the Environment, Transport and Regions*.

[26] S. Emmitt, *Managing Interdisciplinary Projects: A Primer for Architecture, Engineering and Construction*, (Oxon: Spon Press, 2010).

[27] P. Wilkinson, *Construction Collaboration Technologies: The extranet revolution*, (Oxon: Taylor & Francis, 2005).

[28] NIST, “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry”, US Department of Commerce Technology Administration, 2004.

[29] S. Lockley, D. Greenwood, J. Matthews and C. Benghi, “Constraints in Authoring BIM Components for Optimal Data Reuse and Interoperability: Results of Some Initial Tests”, (2013) 2(1) *International Journal of 3-D Information Modeling* 29–44; R. Sacks, I. Kaner, C. Eastman and Y. Jeong, “The

Rosewood experiment—Building information modelling and interoperability for architectural precast facades", (2010) 19 *Automation in Construction* 419–432.

[30] L. Currie, "Building Information Modelling: Its impact on insurance, intellectual property rights and design liability", Society of Construction Law, 2014.

[31] R. Joyce and D. Houghton, "Building Information Modelling and the Law", (2014) 167 (MP3) *ICE Management, Procurement and Law* 114–116.

[32] P. Goodwin, "The PIX Protocol: A risk reduction tool for construction projects", Society of Construction Law, 2004.

[33] R. Davies and C. Harty, "Implementing 'Site BIM': A case study of ICT innovation on a large hospital project", (2013) 30 *Automation in Construction* 15–24.

[34] L. Joia, "Large-scale Reengineering in Project Documentation and workflow at Engineering Consultancy Companies", (1998) 18(3) *International Journal of Information Management* 215–224.

[35] D. Mosey, "BIM and Related Revolutions: A Review of the Cookham Wood Trial Project", Society of Construction Law, 2014.

[36] K. Stowe, S. Zhang, J. Teizer and E. Jaselskis, "Capturing the Return on Investment of All-In Building Information Modeling: Structured Approach", (2014) *Practice Periodical on Structural Design and Construction*.

[37] F. Newbery, "BIM and Professional Risk—Update". (2013) 29(6) Const. L.J. 450–452.

[38] Cabinet Office, "Government Construction Strategy: One Year on Report and Action Plan Update", July 2012.

[39] There are a variety of protocols available, including bespoke protocols. Those which are commonly referred to are: CIC, "Building Information Model (BIM) Protocol", 2013; AIA, "Project Building Information Modeling Protocol", 2013, Document G202; ConsensusDOCS, "Building Information Modeling (BIM) Addendum", 2008, ConsensusDOCS 301.

[40] BSI, BS 1192-4, "Collaborative production of information Part 4: Fulfilling employer's information exchange requirements using COBie—Code of practice", 2014.

[41] Awaiting publication.

[42] In BETA testing phase and includes a digital plan of works and classification system

[43] One of the UK's new alternative models of project procurement to promote ECI and collaborative working.

[44] OGL, "Project Procurement and Delivery Guidance: Using Two Stage Open Book and Supply Chain Collaboration", Kings College London, 2014.

[45] D. Mosey, "BIM and Related Revolutions: A Review of the Cookham Wood Trial Project", Society of Construction Law, 2014.

[46] HM Government, "Cookham Wood Trial Project: Two Stage Open Book under PPC2000". Constructing Excellence, 2014.

[47] NBS, "National Construction Contracts and Law Survey 2013", 2013.

[48] GCCG, "Building Information Modelling (BIM) Working Party Strategy Paper", March 2011.

[49] NEC3, "How to use BIM with NEC3 contracts", 2013.

[50] JCT, "Public Sector Supplement: Fair Payment, Transparency and Building Information Modelling", 2011.

[51] S. Frame, "JCT/SBCC approach to building information modelling (BIM)", (2012) 28(6) Const. L.J. 524–528.

[52] D. Tyerman, "Building information modelling and change management: a single version the truth" (2013) 29(4) Const. L.J. 295–307.

[53] D. Gibbs, "BIM and CPC2013", Constructive Olswang's Construction & Development Blog, 2013.

[54] BSI, PAS 1192-2, "Specification for information management for the capital/delivery phase of construction projects using building information modelling", 2013.

[55] P. Love, P. Davis, J. Ellis and S. Cheung, "Dispute causation: identification of pathogenic influences in construction", (2010) 17(4) *Engineering, Construction and Architectural Management* 404–423.

[56] D. Gibbs, S. Emmitt, K. Ruikar and W. Lord, "An Investigation into whether Building Information Modelling (BIM) can Assist with Construction Delay Claims", (2013) 2(1) International Journal of 3–D Information Modeling 45–52.

[57] CIOB, "Managing the Risk of Delayed Completion in the 21st Century", 2008.

[58] S. Kahn, M. Olbrich, T. Engelke, J. Keil, P. Riess, S Webel, H, Graf, U, Bockholt,and G. Picinbono, "Beyond 3D "As-Built" Information Using AR Enhancing the Building Lifecycle Management", Cyberworlds (CW), International Conference, September 25–27, 2012, 29–36.

[59] D. Gibbs, S. Emmitt, K. Ruikar and W. Lord, "Recommendations on the Creation of Computer Generated Exhibits for Construction Delay Claims", (2014) 30(4) Const. L.J. 236–248.

[60] BD, "Investing in BIM: A Guide for Architects", 2014.

[61] E. Moore, "Radar for dispute avoidance" (2013) 24(10) Cons. Law 6–7.

[62] M. Harris, "Is BIM winning hearts and minds?" (2012) 23(10) Cons. Law 6–7.

[63] N. Greenwald, "A Creative Proposal for Dispute Systems Design for Construction Projects Employing BIM", (2013) 5 *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* 2–5.

APPENDIX C JOURNAL PAPER 3

Gibbs, D., Emmitt, S., Lord, W. and Ruikar, K. (2015). BIM and Construction Contracts - CPC 2013's Approach. *Proceedings of the ICE - Management, Procurement and Law*, 168(6), pp.285-293.

BIM and Construction Contracts – CPC 2013's Approach

ABSTRACT

Building Information Modelling (BIM) changes the way information is generated, managed and communicated between project team members. It is gaining international attention as a potential way of improving the efficiency of the construction industry but, despite the recognised benefits of BIM, perceived barriers are restricting its adoption. Some of these barriers could be addressed through standard forms of construction contract. The CIOB's Complex Projects Contract 2013 (CPC 2013) is the first standard form of construction contract to include BIM clauses in its provisions and appendices. To investigate how CPC 2013 attempts to address the perceived barriers of BIM adoption and promote working in a BIM environment, a content analysis is undertaken. The research found that although CPC 2013 addresses some of the perceived barriers, in its standard form, the contract may require amendments and special conditions to support a "Level 2" environment.

KEYWORDS

BIM; Claims; Contracts; Complex Projects Contract; CPC 2013; Disputes; Level 2

INTRODUCTION

Over 75% of construction organisations around the world have an underperforming project (KPMG, 2013). This can be attributed to quality issues, cost overruns and longer project durations which, if unresolved, could develop into dispute (Kumaraswamy, 1997).

Disputes are becoming increasingly likely on construction projects (Cheung, 2013; NBS, 2013) but they have a negative effect on the industry. The global average construction dispute is valued at US$31.7million, lasts 12.8months (EC Harris, 2013) and generates indirect costs of lost productivity, stress and fatigue, loss of future work, reduced profit, and tarnished reputation (Love, 2010). Furthermore, skillsets outside of the construction industry are employed to resolve the dispute which results in money migrating to other sectors.

Disputes can arise out of the inefficiencies of the construction industry but despite the publication of numerous documents acknowledging the industries waste, there has been little improvement (Latham, 1994; Egan, 1998; NAO, 2001; CIOB, 2008; Wolstenholme, 2009). In an attempt to bring about positive change, the UK has defined a set of strategy objectives (Cabinet Office, 2011). One of the strategy objectives is Building Information Modelling (BIM).

BIM has gained international recognition as way of improving the efficiency of the construction industry (McGraw Hill, 2014a) and the associated benefits are thought to reduce the number of delays and disputes (PAS 1192-2, 2013). However, it can be argued that the uptake of BIM has been limited by perceived barriers to its adoption (Eastman, 2011), some of which could be overcome through a construction contract.

The CIOB's Complex Project Contract (CPC 2013) is the first standard form of construction contract to include BIM in its clauses and appendices. Like the UK Government, CPC 2013 recognises the inefficiencies of the construction industry and acknowledges the potential of BIM to make a step change.

There is little published research investigating the incorporation of BIM into standard forms of construction contract and, as a relatively new contract, there is a limited amount of independently published research on CPC 2013. Therefore, the objective of this paper is to add an original contribution of knowledge by investigating how CPC 2013 attempts to facilitate a BIM environment. This is achieved through a content analysis.

BACKGROUND

Building Information Modelling (BIM)

There is a plethora of inconsistent BIM literature available which has led to the term “BIM” meaning different things, to different people, around the world (NBS, 2013a). In order to establish consistent terminology, this paper is written in relation to the UK’s perspective of BIM.

As one of the leaders in the development of BIM (HM Government, 2012), the UK has produced numerous documents to support their Government’s mandate of a “fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016” (Cabinet Office, 2011). This is commonly referred to as “Level 2”.

The focus of “Level 2” working is on collaboration. “Level 2” advances past unmanaged computer-aided design (CAD) (“Level 0”) and managed CAD, which may include 3D design (“Level 1”) (GCCG, 2011). Instead, in a “Level 2” environment, each project team member is required to create a virtual 3D model of their work using object-oriented software and follow a managed approach to information creation and exchange.

Object-oriented software is more developed than traditional CAD and uses “smart” objects which interact with each other through their individual properties and awareness of space (Eastman, 2011). The “smart” objects represent physical components and allow information to be embedded or linked to each item. This opens up the opportunity for multiple dimensions (nD) (Ding, 2014) which could include the construction programme (4D), cost information (5D) and facilities management information (6D) (RIBA, 2012). These multiple dimensions are distinctly different from the various “Levels”. The multiple dimensions can be utilised in a “Level 2” environment but they are not a minimum requirement under the UK’s “Level 2” mandate. Nevertheless, even if multiple dimensions aren’t used, a mass of data is likely to be generated within a “Level 2” environment and is required to be managed.

Under “Level 2” each project team member is required to deliver a certain Level of Development (LoD) at specified stages of the project (AIA, 2008; BIM Forum, 2013; NATSPEC, 2013; PAS 1192-2, 2013). At each specified stage, the individual models are brought together by a BIM coordinator to create a “Federated Model”. To facilitate the input, management and exchange of this data, a Common Data Environment (CDE) is required which will act as a single point of reference for all project information (PAS 1192-3, 2013).

The stages after “Level 2” are not well established. It is likely that “Level 3” and beyond will involve a fully open process, where all project team members can work on the same project information simultaneously (GCCG, 2011). This truly collaborative process could be developed to include interoperability for smart cities, nano-second procurement and performance, and robotics and autonomous systems (CIC, 2014).

Some organisations may confuse “Levels" or just undertake an aspect of each “Level”. This can create situations such as “Lonely BIM”, where an organisation does not collaborate and uses elements of BIM for the sole benefit of their business (Das, 2014; McGraw Hill, 2012).

Benefits of “Level 2” BIM

The benefits associated with “Level 2” BIM can be summarised as (BD, 2014; McGraw Hill, 2014a):

- better collaboration and improved team relationships;
- ease of access to project/asset information;
- easier analysis of the ongoing project/asset;
- concepts are easier to realise and alternatives easier to formulate;
- improved workflow cycle time and reduced waste (double working);
- reduced lifecycle cost and schedule growth as well as improved certainty; and,
- more sustainable construction and green performance of the asset.

However, despite the wide range of benefits associated with “Level 2”, perceived barriers to its adoption exist (Eastman, 2011).

Perceived barriers to BIM adoption

Legal and contractual

Although little is expected to change in terms of copyright law, contracts and insurance within a "Level 2" environment (GCCG, 2011), it can be argued that BIM alters relationships and blurs the lines of the roles and responsibility of project team members which may affect the current legal and contractual position (Harris, 2012). This has generated uncertainty (Currie, 2014) and has led to promoters and participants asking (Joyce, 2014):

- Who owns the federated model?
- Who is responsible for creating, analysing and updating project information, including the federated model?
- When will information be delivered and how much can it be relied upon?
- What is the priority of documents?

Collaboration

BIM is more than just 3D modelling and information exchange; it is a collaborative way of working (HM Government, 2012). Therefore, it requires (Barratt, 2004):

- a collaborative culture;
- external and internal trust and mutuality;
- information exchange;
- technology and tools;
- process integration; and,
- strategic planning.

Collaboration can improve project performance (Greenwood, 2012) but it can face various forms of resistance (Wilkinson, 2005). This can result in some individuals and project teams becoming focused on "silo" working which, in some cases, can develop into an adversarial attitude towards business. Therefore, the sharing of power required to support a collaborative environment could be difficult for some to accept (Emmitt, 2010).

Furthermore, the development of technologies and tools to support collaborative working face unique demands (Grudin, 1994). This includes interoperability issues between different software platforms, which are estimated to cost the United States capital facilities industry around USD$15.8 billion per year in addition to significant inefficiency and lost opportunity costs (NIST, 2004). Interoperable software is a fundamental component of "Level 2", especially for the exchange of graphical models. While attempts have been made to solve this issue through the development of Industry Foundation Classes (IFC) which acts as a neutral, open, platform for graphical model exchange (Eastman, 2010), a lack of confidence regarding IFC remains within the construction industry (Jeong, 2009; Sacks, 2010; Lockley, 2013).

Use and management of information

The construction industry has been slow to embrace the use of electronic information, particularly for site management activities (Davies, 2013). Even when electronic information is used it is not always well managed (CIOB, 2008) which can make its retrieval challenging (Joia, 1998).

Within a "Level 2" environment, project team members are expected to generate and exchange information in electronic format. Paper documentation is limited and a virtual model is required. This may not be common practice for some of the project team. Given the enhanced speed in which information can be exchanged and the mass of data which could be generated in a "Level 2" environment, the problems associated with electronic information exchange could be exacerbated. Additionally, the clear interface between project team members challenges the segregation of conventional procurement. Therefore, the release of information can no longer be governed by what is 'reasonable' and the improved transparency of information brings the responsibility to warn project team members of the potential impact of any changes (Mosey, 2014).

Investment

BIM, as a process, is supported by software, hardware and training. To assist the successful transition from conventional practice to a “Level 2” environment, time and money should be invested into each of these items.

The purchasing, maintenance and upgrading of software which has been developed to support BIM tends to be more expensive than conventional CAD packages (Stowe, 2014). Furthermore, the minimum hardware requirements which are required to support this software may not be available on standard machines. In order to operate the new hardware and software, as well as to understand the new process of working, training will be required.

Addressing the perceived barriers

Key documents and processes

Following the UK Government BIM mandate, various documents have been published to support “Level 2” adoption by addressing some of the perceived barriers. These documents include:

1. CIC BIM Protocol (2013);
2. PAS 1192-2 (2013);
3. PAS 1192-3 (2014); and,
4. BS 1192-4 (2014).

Additional publications are expected, which include a digital plan of work (dPOW), specification for BIM security and developments in classification systems. All of these documents are intended to be used in conjunction with existing recommended practice and have been designed for use with all contract forms.

Standard forms of contract

Although little change is required for standard forms of construction contract to support “Level 2” adoption (GCCG, 2011), it is not common for BIM to be referenced or adopted in contracts (NBS, 2013b). The Joint Contract Tribunal (JCT) and The New Engineering Contract (NEC) suites of contracts are two of the most commonly used standard forms of construction contract (NBS, 2013b; RICS, 2011) and attempts have been made to make them compatible for a “Level 2” environment.

NEC3 published “How to use BIM with NEC3 Contracts” (NEC3, 2013) which focuses on the creation of “the model”. The guide advises on how the CIC BIM protocol can be incorporated into some of NEC3’s contract forms and offers guidance on inserting technical requirements into the contract, as well as addressing the project team member’s rights and liabilities through additional conditions of contract (“Z” clauses).

JCT have published a Public Sector Supplement which suggests steps and modifications to be made when design work and information exchange is governed by a BIM protocol (JCT, 2011). The document consists of schedules of modifications for a variety of JCT’s contracts and sub-contracts, one of which is the Constructing Excellence Contract which encourages collaborative working (Frame, 2012).

Despite the popularity of the NEC3 and JCT suite of contracts on conventional construction projects, PPC 2000 was the contract chosen for the UK government’s “Level 2” BIM trial projects. The multi-party contract was favoured as it governs the duration of the procurement process and promotes collaboration by bringing in key project participants at the design phase of the project (Tyerman, 2013). On the trial projects, no amendments were made to the contract in respect of BIM; neither was a BIM protocol used. Instead, a set of mutual intellectual property licences were created, linking a series of deadlines to the contract under PPC 2000’s multi-party structure (Mosey, 2014).

In addition to these forms of contract, CPC 2013 is the first standard form of construction contract to include BIM provisions in its clauses and appendices.

CPC 2013

CPC 2013 is designed for international building and construction projects which cannot be managed by intuition alone. A variety of procurement methods can be used under the one form of contract along with the option of using special conditions for each project (Pickavance, 2014).

The contract was developed to address research which reported that 60% of complex projects were not delivered on time or within budget and that inadequate progress records were kept for their management (CIOB, 2008). Therefore, unlike other forms of construction contract, CPC 2013 is prescriptive on programming, resource data and record keeping in relation to recommended best practice (CIOB, 2011). The aim of this proactive, open, scientific approach is to reduce the likelihood and severity of disputes (Fenwick Elliott, 2014).

To facilitate this, the contract utilises 21st century methods of working. No paper documents are required for communication and the contract focuses on collaboration and transparency of information in order to manage risk, time, cost and quality. To administer this, the contract includes new roles such as the Project Time Manager and Data Security Manager.

The contract is designed to work on both BIM and conventional projects. While other standard forms of contract require amendments for "Level 2" use, CPC 2013 includes BIM in its clauses and appendixes and is supported through the incorporation of a BIM Protocol.

METHODOLOGY

As a relatively new contract, there is little peer reviewed literature or project data associated with CPC 2013. Publications which analyse how other standard forms of construction contract overcome key issues have undertaken a content analysis (Patterson, 2013). A content analysis makes inferences from communications in relation to the context of their use and, as a flexible research method, is widely used for analysing text data (Krippendorff, 2010).

Content analysis has been criticised for focusing attention and bias; however, this research maintains that it is an appropriate methodology for analysing construction contracts and uses a directed approach (Hsieh, 2005). This approach follows a structured process which reviews the literature to identify existing theory and key concepts about the perceived barriers of BIM adoption. These barriers serve as a framework against which the clauses and appendices of CPC 2013 are analysed and are used to guide the discussion of the findings.

ANALYSIS

Legal and contractual

Under CPC 2013, copyright and ownership rights remain vested in the creator, with particular reference to the contractor. If a contractor is required to contribute to a model and/or federated model, or if the contractor is required to design the whole works, the contribution, and information derived from its input, remains the copyright of the contractor.[10] Licences and sub-licences are to be granted to allow the use of this information for its permitted purpose[11] and the employer can use the contractors design for certain purposes.[12] To ensure commercially or security sensitive information is not made available to those who should not have access,[13] a Data Security Manager is employed.[14]

[10] CPC 2013 Clauses 11.2 and 11.3

[11] CPC 2013 Clause 11.1.2

[12] CPC 2013 Clause 10.2.3

[13] CPC 2013 Clause 21

[14] CPC 2013 Clause 11.4

An overview of the project team member's roles and responsibilities are provided in the contract's user notes[15] and additional listed persons can be included in the contract.[16] The responsibility of creating, analysing and updating project information to a required standard, at a set delivery period, are set out in Appendix C of the contract. The works are split into six design stages, with a particular LoD required at each stage.[17] The model is to only be used for the design stage it was intended[18] and the design contributor for each design element, which is referenced to Uniclass, is assigned to each stage of the project.[19] The models can be brought together to create a federated model and maintenance of the federated model is to be undertaken by a design coordination manager.[20]

The priority of documents are established in the contract, with preference given to the federated model and the information derived from it over the use of technical drawings.[21] A BIM protocol is required for the maintenance of the model under the contract;[22] however, if there is a difference between the contract and the protocol, the contract will prevail unless stated in the contracts special conditions.[23]

Collaboration

CPC 2013 introduces itself as a contract which promotes the use of technology and requires a collaborative, transparent, approach to working which is hoped to assist the delivery of the project within time and budget.[24] A collaborative environment is created through the conditions of the contract under which the project teams have a clear purpose and are required to co-operate in a spirit of mutual trust and fairness.[25]

The use of collaborative software, particularly a CDE which allows project team members to exchange electronic information through a web-based server, is promoted in CPC 2013; however, other means of information exchange are allowed under the contract.[26] Documents and information are to be exchanged in native file format and the software, hardware and data associated with the information exchange platform are to be updated and maintained by the party identified in the special conditions.[27]

The working schedule and progress records require the software and its version to be stated.[28] If BIM is adopted on the project whereby the contractor designs the whole works, the contractor is responsible for the suitability and integrity of the selected software and all information extracted from the model.[29]

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[15] CPC 2013 User Notes, pg42-46

[16] CPC 2013 Appendix B: Listed Persons

[17] CPC 2013 Appendix C: Table 1

[18] CPC 2013 Appendix C: C1

[19] CPC 2013 Appendix C: Table 2

[20] CPC 2013 User Notes, pg44 and pg72

[21] CPC 2013 Clause 3.3

[22] CPC 2013 Clauses 11.1.4 and 11.3.3

[23] CPC 2013 Clause 11.4

[24] CPC 2013 Conditions: Introduction

[25] CPC 2013 Clause 5.1

[26] CPC 2013 Clause 2.4.7

[27] CPC 2013 Clause 5.15

[28] CPC 2013 Appendix D1 and E2

[29] CPC 2013 Clause 11.3.4

Use and management of information

CPC 2013 acknowledges 21st century ways of working[30] and does not require any information to be printed and delivered in hard copy format alone.[31] Instead, the contract promotes the exchange of electronic information, preferably through a CDE, which is to be shared in native file format to assist with information transparency.[32]

Information is to be managed and published through the chosen information exchange platform.[33] If the contractor fails to publish information at a required time, a procedure is to be followed[34] which could result in an external party being employed to create the required information at the cost of the contractor.[35]

If the project adopts BIM, the model is to be developed in accordance with Appendix C[36] and the same coding structure is to be used for the working schedule and the model.[37] The model and information derived from it have preference over conventional construction documents[38] and if any project team member becomes aware of an event which could interfere with the project, they are to issue an early warning.[39]

Investment

Although not a contract requirement, CPC 2013 recommends that the purchase, installation and training in software and hardware required to fulfil the conditions of the contract should be borne by the organisation using them as they will add value to the investing organisation after the project is complete.[40]

DISCUSSION

Similarities between CPC 2013 and BIM

Whilst undertaking the content analysis, similarities between CPC 2013 and BIM emerged (Gibbs, 2013). Both CPC 2013 and BIM:

- require transparent, reliable, electronic information exchange;
- aim to produce high value project information which can be used to make informed decisions and increase certainty for project team members;
- require front end investment in an attempt to reduce the likelihood and severity of future problems;
- require a collaborative approach.

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[30] CPC 2013 Conditions: Introduction

[31] CPC 2013 User Notes, pg47

[32] CPC 2013 Clause 2.4.7

[33] CPC 2013 Clause 2.4.7

[34] CPC 2013 User Notes: Flow Chart No.1 – Failure to Publish, pg83

[35] CPC 2013 Clause 25.2

[36] CPC 2013 Appendix C: Table 1 and 2

[37] CPC 2013 Appendix D: Paragraph D9

[38] CPC 2013 Clause 3.3 and 3.4.1

[39] CPC 2013 Clause 36

[40] CPC 2013 User Notes, pg39

As a consequence, a synergy between the two exist and even without specific reference to BIM, CPC 2013 creates and environment which goes some way to address the perceived barriers of BIM adoption.

Addressing the barriers

Legal and contractual

Within a “Level 2” environment, project team members are required to work in isolation to produce information. In terms of output, apart from the individual 3D virtual models, it could be argued that little changes from conventional practice. Therefore, CPC 2013’s approach of allowing the creator to retain ownership and grant licences to others for their use appears feasible. However, given that CPC 2013 is a two-party contract between the client and the contractor, the application of these terms only relates to the contractor and would need to be expanded into other forms of contract to encompass all project teams.

The roles and responsibilities of each project team member are described in the contracts user notes and a matrix is used to assign project team members the responsibility of creating, analysing and updating specific project information at different stages of the project. The contract explicitly states that this information should only be used for the design stage in which it was intended. However, it could be argued that the matrix is not adequate for this purpose and that the contract is reliant on the BIM Protocol to specify how the model and/or federated model should be maintained. Nevertheless, the use of matrices for the purpose of assigning responsibility is consistent with other key BIM documents. Although they may not be directly compatible because CPC 2013 uses different LoD and design stages, the contract does allow the matrix to be replaced or modified to suit the project.[41] Therefore, care should be taken to ensure consistency between documents.

Given the masses of data involved in a “Level 2” environment and the level of transparency required under the contract, the creation of the data security manager is useful for the successful management and security of project information. In the event the models are federated and changes are made, the software could be capable of identifying what change has been made and who made it.

Conflicts between terminology and priority of documents may occur between the contract and the selected protocol. Whilst CPC 2013 states that the terms of the contract shall prevail over a BIM protocol, the CIC BIM Protocol (2013) states that the protocol will prevail over other contract documents.[42] Therefore, amendments may be required to the documents.

Collaboration

CPC 2013’s definition of BIM focuses on the term “Model” and not collaboration; however, the requirements of a collaborative culture and trust are set out in the introduction of CPC 2013’s user notes and under the obligations of the parties. The wording used in Clause 5.1 is comparable to clauses found in other standard forms of contract and, although similar clauses have been acknowledged by the courts,[43] the impact of such a provision on the other clauses in a contract is unclear (Barlow, 2011). Therefore, it is uncertain whether Clause 5.1 alone can enforce aspects of collaborative working. Recognising this, CPC 2013 attempts to reinforce the idea of collaboration by setting a collective goal and promoting openness through prescriptive contract requirements. Nevertheless, the contract cannot instantly change the nature or culture of construction works; neither can it change some of the ingrained attitudes towards collaboration. Therefore, adversarial behaviour could still remain under the contract and restrict collaboration.

Although not only native files are required to be exchanged, the requirement for information to be produced and shared in electronic format, along with the native file, should encourage collaboration and improve trust as project team members have the opportunity to interrogate information in the format it was created. However, to realise this benefit, the appropriate software to open the file is required. Given

[41] CPC 2013 Appendix C: Footnote 6

[42] CIC BIM Protocol: Clause 2.1

[43] Northern Ireland Housing Executive v Healthy Buildings (Ireland) Ltd [2014] NICA 27

the specialist software which has been developed to support BIM, it is unlikely that software licences will be held by all of the project team members (McGraw Hill, 2014b), so the native files may not be of assistance.

Furthermore, the specification of software requirements only applies to the working schedule and progress records. While this requirement goes some way to improve interoperability issues, the problems associated with interoperability are far reaching and are likely to exist between other forms of information exchange, most notably the virtual model. Unless this is addressed in the appropriate protocol, collaboration could be inhibited.

A platform for collaborative information exchange is provided through the CDE. The contracts defined process for managing and using information allows the CDE to be used for shared understanding between project team members and can be effective if it is used correctly. However, the use of a CDE is not compulsory under CPC 2013 and the alternative options, file transfer protocol or email, might not support collaboration on complex projects as effectively.

Although the prescriptive nature of CPC 2013 drives the project team towards a common goal and ensures that recommended practice is upheld, it does provoke debate as to whether the contract trusts individuals and organisations to perform their roles. The contract also recognises the adversarial nature of the construction industry and establishes a procedure to reduce the frequency and severity of disputes. While some may take the stance that CPC 2013 is expecting the collaborative environment to fail, others will acknowledge that conflicts are a natural part of the construction process and see value in a precautionary, defined, dispute resolution process.

Use and management of information

CPC 2013's promotion of electronic information and its preference to use a CDE to manage project information provides a suitable foundation for a "Level 2" environment. If used correctly, a CDE will assist with managing the high volume of data which is likely to be produced in "Level 2" projects. However, the contract does not enforce the use of a CDE and allows the use of alternative options for information distribution. This could include file transfer and email, which might not efficiently manage high levels of data.

The LoD and design author responsibility matrices assist with the production and management of information and the contracts failure to publish procedure should encourage the accurate production and reliable delivery of information. However, this process relies on the project stages being well established and understood by all project team members. Furthermore, CPC 2013's uses Uniclass as its classification system, which may not be favoured by some project team members, especially since Uniclass 2 was published to support BIM (Monteiro, 2014).

Given the need for collaboration and transparent information, it is likely that project team members will realise events which could have a negative impact on the project. The system of providing early warnings is a useful and well established way of doing this.

Although the 3D virtual model is intended to be an accurate representation of the works, object-orientated software cannot always produce the detail required, so the creation of additional information may be necessary. The contract acknowledges this stating that the federated model should be used where applicable, but this could be left open to interpretation.

Some of the documents published by the UK to support their BIM mandate offer guidance on the use and management of information throughout the lifecycle of a BIM project. As the contract was released before the publication of various key documents, there is no reference to these publications in the contract. However, the use of these documents is encouraged in some protocols and they could be made an explicit contractual requirement.

Investment

The contract does not explicitly state who should pay for investment. Although CPC 2013 recommends that the cost of software, technology and training is to be borne by the organisation using them, some may argue that multiple sources benefit from the investment; therefore, it should be a project cost.

The future of BIM and its application with construction contracts

Aspects of technology are developing at an exponential rate. Some developments will be made to address specific construction problems, while the technological developments in other sectors may have a transferable benefit to the construction industry. Therefore, the move towards electronic information exchange and 3D virtual modelling, as required in a “Level 2” environment, should see the amount of technology applied on construction projects increase.

Current developments, such as the use of handheld devices for contemporaneous record keeping (Davies, 2013) and the use of the virtual model to support with time management (Gibbs, 2014), could assist with the requirements of CPC 2013 and other construction contracts. However, if the use of technology starts to alter the legal position and relationships between project team members, the contract and supporting information may not be appropriate. Therefore, any advance past “Level 2” will require further consideration.

CONCLUSION

CPC 2013 goes some way to facilitate BIM adoption by attempting to overcome the perceived barriers associated with working in a “Level 2” environment. Like NEC3 and JCT, CPC 2013 requires a BIM Protocol to be incorporated into the contract. In standard form, the NEC3 and JCT suite of contracts do not reference BIM, but CPC 2013 makes the incorporation of a BIM protocol mandatory and references BIM in its clauses and appendices. This could provide project team members with the confidence they require to adopt BIM.

However, in its standard form, CPC 2013 may not facilitate a true “Level 2” environment and the inclusion of special conditions and amendments to the contract and protocol might be required. Such amendments may not be required under PPC 2000. As all of the standard forms of contract are only compatible with “Level 2” working, care should be taken if project team members wish to advance past this “Level”.

In contrast to the other standard forms of contract, CPC 2013 is prescriptive in nature which helps encourage openness of information and drives the project teams towards a common goal. This could help facilitate collaborative working, which forms the foundation of BIM. However, CPC 2013 appears to have suffered from a release date prior to the UK’s publication of key documents to support BIM and as a consequence, key documents are not present in the contract. Furthermore, CPC 2013 appears to focus on BIM as a virtual model, instead of a collaborative process of working, with emphasis on the construction stage more so than the lifecycle of the built asset. Although the contract clauses attempt to support collaboration and the process of structured electronic information exchange, it could be argued that CPC 2013 facilitates a “Lonely BIM” environment as the contract only exists between the client and the contractor. Other standard forms of contract could be employed between the client and other project team members to establish a “Level 2” environment, but inconsistencies may occur and the legal framework could become difficult to manage. Therefore, there would be value in drafting additional contracts which are consistent with CPC 2013 and could exist between the client and other project team members.

There is little research investigating how standard forms of construction contract attempt to establish a “Level 2” environment and little published research specifically on CPC 2013. It is hoped that this research will act as a platform for further investigation and discussion which could investigate and compare how other standard forms of construction contract facilitate a BIM environment. Further investigation is also required to understand the amendments and additions required for CPC 2013, and other standard forms of construction contract, to support a “Level 2” environment and the relationship with other BIM documents. Furthermore, as a relatively new contract, CPC 2013 lacks detailed review and practical exposure, so the analysis of the contract in a live environment would also be of value.

Despite this, BIM and CPC 2013 attempt to make a positive change to the construction industry, especially in relation to the proactive management of cost and time on construction projects, and should be commended. It is hoped that individually, or collectively, CPC 2013 and BIM can reduce the likelihood and severity of construction disputes and further research in the form of an Engineering Doctorate (EngD) is being undertaken into this field.

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REFERENCES

AIA., 2008. Document E202: *Building Information Modeling Protocol Exhibit*.

Barlow, M., 2011. The NEC Construction and Engineering Contract: To Amend or not to Amend? *Society of Construction Law*.

Barratt, M., 2004. Understanding the meaning of collaboration in the supply chain. *Supply Chain Management: An International Journal*, 9(1), 30-42.

BD., 2014. *Investing in BIM: A Guide for Architects*.

BIM Forum., 2013. Level of Development Specification: For Building Information Models. August 22, 2013.

BS 1192., 2007. Collaboration production of architectural, engineering and construction information – Code of Practice. *British Standard*.

BS 1192-4., 2014. Collaborative production of information – Part 4: Fulfilling employer’s information exchange requirements using COBie – Code of practice. *BSI Standard Publication*.

Cabinet Office., 2011. Government Construction Strategy. May 2011.

CIC., 2013. Building Information Model (BIM) Protocol.

CIC., 2014. Built Environment 2050: A Report on Our Digital Future.

CIOB., 2008. Managing the Risk of Delayed Completion in the 21st Century. *The Chartered Institution of Building*.

CIOB., 2011. *Guide to good practice in the management of time in complex projects*. West Sussex: Wiley-Blackwell.

Cheung, S., and Pang, K., 2013. Anatomy of Construction Disputes. *Journal of Construction Engineering and Management*, 139, 15-23.

Currie, L., 2014. Building Information Modelling: Its impact on insurance, intellectual property rights and design liability. *Society of Construction Law*.

Das, M., Cheng, J., Kumar, S., 2014. *BIMCloud: A Distributed Cloud-based Social BIM Framework for Project Collaboration*. Computing in Civil and Building Engineering.

Davies, R., and Harty, C., 2013. Implementing 'Site BIM': A case study pf ICT innovation on a large hospital project. Automation in Construction, 30, 15-24.

Ding, L., Zhou, Y., and Akinci, B., 2014. Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD. *Automation in Construction*, 46, 82-93.

Eastman, C., Jeong, Y., Sacks, R., and Kaner, I., 2010. Exchange Model and Exchange Object Concepts for Implementation of National BIM Standards. *Journal of Computing in Civil Engineering*, 24, 25-34.

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*. 2 ed. New Jersey: Wiley and Sons.

EC Harris., 2013. Global Construction Disputes: A Longer Resolution.

Egan, J., 1998. Rethinking Construction: report of the construction task force on the scope for improving the quality and the efficiency of UK construction. *Department of the Environment, Transport and Regions*.

Emmitt, S., 2010. *Managing Interdisciplinary Projects: A primer for architecture, engineering and construction*. Spon Press: Oxon.

Fenwick Elliott., 2014. The CIOB Complex Projects Contract 2013. *Insight*, issue 33.

Frame, S., 2012. JCT/SBCC approach to building information modelling (BIM). *Construction Law Journal*.

GCCG., 2011. Building Information Modelling (BIM) Working Party Strategy Paper. *A report for the Government Construction Client Group*. March 2011.

Gibbs, D., 2013. BIM and CPC 2013. *Constructive.* Olswang's Construction & Development Blog.

Gibbs, D., Emmitt, S., Ruikar, K., and Lord, W., 2014. Recommendations on the Creation of Computer Generated Exhibits for Construction Delay Claims. *Construction Law Journal*, 30(4), 236-248.

Greenwood, D., and Wu, S., 2012. Establishing the association between collaborative working and construction project performance based on client and contractor perceptions. *Construction Management and Economics*, 30, 299-308.

Grudin, J., 1994. Groupware and social dynamics: Eight challenges for developers. *Communications of the ACM*, 37(1), 92-105.

Harris, M., 2012. Is BIM winning hearts and minds? *Construction Law*, December 2012.

HM Government., 2012. *Building Information Modelling - Industrial strategy: government and industry in partnership*.

Hsieh, H., and Shannon, S., 2005. Three Approaches to Qualitative Content Analysis. *Qualitative health Research*, 15, 1277-1288.

JCT., 2011. Public Sector Supplement: Fair Payment, Transparency and Building Information Modelling.

Jeong, Y., Eastman, C., Sacks, R., and Kaner, I., 2009. Benchmark tests for BIM data exchanges of precast concrete. *Automation in Construction*, 18, 469-484.

Joia, L., 1998. Large-scale Reengineering in Project Documentation and workflow at Engineering Consultancy Companies. *International Journal of Information Management*, 18(3), 215-224.

Joyce, R., and Houghton, D., 2014. Building Information Modelling and the Law. *ICE Management, Procurement and Law*, 167 (MP3), 114-116.

KPMG., 2013. Ready for the next big wave? *Global Construction Survey 2013*.

Krippendorff, K., 2010. Content analysis. In N. Salkind (Ed.), *Encyclopedia of research design*. (pp. 234-239). Thousand Oaks, CA: SAGE Publications.

Kumaraswamy, M., 1997. Conflicts, claims and disputes in construction. *Engineering, Construction and Architectural Management*, 4(2), 95-111.

Latham, M., 1994. Constructing the Team: Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry: Final Report. *H.M.S.O*.

Lockley, S., Greenwood, D., Matthews, J., and Benghi, C., 2013. Constraints in Authoring BIM Components for Optimal Data Reuse and Interoperability: Results of Some Initial Tests. *International Journal of 3-D Information Modeling*, 2(1), 29-44.

Love, P., Davis, P., Ellis, J., Cheung, S., 2010. Dispute causation: identification of pathogenic influences in construction. *Engineering, Construction and Architectural Management*, 17(4), 404-423.

McGraw Hill., 2012. The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007-2012). *SmartMarket Report*.

McGraw Hill., 2014a. The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation With Building Information Modeling. *SmartMarket Report.*

McGraw Hill., 2014b. The Business Value of BIM for Owners. *SmartMarket Report*.

Monteiro, A., Mêda, P., and Martins, J., 2014. Framework for the coordinated application of two different integrated project delivery platforms. *Automation in Construction*, 28, 87-99.

Mosey, D., 2014. BIM and Related Revolutions: A Review of the Cookham Wood Trial Project. *Society of Construction Law*.

NAO., 2001. Modernising Construction. *Report by the controller and auditor general HC 87 Session 2000-2001: 11 January 2001*. London, England: The Stationery Office.

NATSPEC., 2013. BIM and LOD: Building Information Modelling and Level of Development. *BIM Paper*, NBP 001, November 2013. Construction Information Systems Limited.

NBS., 2013a. NBS International BIM Report 2013.

NBS., 2013b. National Construction Contracts and Law Survey 2013.

NEC3., 2013. How to use BIM with NEC3 contracts.

NIST., 2004. Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry. *U.S Department of Commerce Technology Administration*.

PAS 1192-2., 2013. Specification for the information management for the capital/delivery phase of construction projects using building information modelling. *BSI*.

PAS 1192-3., 2014. Specification for information management for the operational phase of assets using building information modelling. *BSI*.

Patterson, R., and Trebes, B., 2013. NEC contracts for design-build-operate contracts. *Proceedings of the Institution of Civil Engineers Management Procurement and Law*, 166, 260-268.

Pickavance, K., 2014. The CIOB Complex Projects Contract 2013. *Society of Construction Law*.

RIBA., 2012. *BIM Overlay to the RIBA Outline Plan of Work*. London, England: RIBA Publishing.

RICS., 2011. Contracts in Use: A Survey of Building Contracts in Use during 2010. *Davis Langdon*.

Sacks, R., Kaner, I., Eastman, C., and Jeong, Y., 2010. The Rosewood experiment – Building information modelling and interoperability for architectural precast facades. *Automation in Construction*, 19, 419-432.

Stowe, K., Zhang, S., Teizer, J., and Jaselskis, E., 2014. Capturing the Return on Investment of All-In Building Information Modeling: Structured Approach. *Practice Periodical on Structural Design and Construction*.

Tyerman, D., 2013. Building information modelling and change management: a single version the truth. *Construction Law Journal*.

Wilkinson, P., 2005. *Construction Collaboration Technologies: The extranet evolution*. Oxon: Taylor & Francis.

Wolstenholme, A., 2009. Never Waste a Good Crisis: A Review of Progress since Rethinking Construction and Thoughts for Our Future. Construction Excellence.

APPENDIX D JOURNAL PAPER 4

Gibbs, D., Emmitt, S., Ruikar, K. and Lord, W. (2014). Recommendations on the Creation of Computer Generated Exhibits for Construction Delay Claims. *Construction Law Journal*, 30(4), pp.236-248.

Recommendations on the Creation of Computer Generated Exhibits for Construction Delay Claims

INTRODUCTION

Over 60 per cent of complex construction projects encounter delay.[1] If the cause of the delay is not an affected project team member's contractual risk, they are entitled to additional time to complete the work and/or financial compensation. In order to obtain this a claim must be submitted but if the claim cannot be resolved it may develop into a dispute.[2]

The global average construction dispute costs US$31.7 million, lasts 12.8 months[3] and generates indirect costs of lost productivity, stress and fatigue, loss of future work, reduced profit, and tarnished reputation.[4] Furthermore, skillsets outside of the construction industry are employed to resolve the dispute resulting in money migrating to other sectors which, in turn, has an overall negative effect on the whole of the construction industry.

In order to minimise the likelihood and severity of disputes, demonstrative evidence could be used to make construction delay claims clearer.[5] Computer Generated Exhibit's (CGE) are a form of demonstrative evidence and guidance on their preparation for the courtroom is discussed in the literature.[6] However, no research analyses how CGE are being used to support delay claims at any stage of a construction claim or dispute. To fill the knowledge gap, this paper analyses how two different CGE, which were created as simulations, were developed to support the same delay claim. Identifying the benefits and limitations of each simulation, recommendations on the creation of CGE for construction delay claims are made.

KEYWORDS

Audiovisual aids; Civil evidence; Computer-generated works; Construction disputes; Delay.

BACKGROUND

Delays

The term delay is exhaustively used in the construction industry; however, no standard form of construction contract defines the term due to the comparative nature in which it is used.[7] In this paper, the term delay refers to the non-completion of works by a date agreed in the construction contract.[8] Therefore, the process of analysing delays can be viewed as the forensic investigation into an issue which has caused a project to overrun on time.[9] This is distinctly different from disruption, a term generally conjoined with delay, which investigates loss of efficiency due to a disturbance, hindrance or interruption to a contractors working method.[10] The topic of disruption is not covered in this paper but both can become intertwined and result in construction claims.

Subject to the claiming party, different forms of compensation are available depending on how the delay is categorised.[11] On the one hand, the client can claim unliquidated or liquidated damages which protect their investment if the project is not completed by the contract completion date. On the other hand, the contractor can claim an extension of time and/or loss and expense if the project is delayed for reasons beyond their control. In order for the affected party to receive compensation, a claim must be submitted which demonstrates causation, liability and quantum.[12] The burden of proof is placed with the claimant to prove each of these by showing on the balance of probabilities[13] but this can prove challenging.

Construction programmes are the most common way to represent the cause and effect of delays and there are a variety of methodologies available to do this. The choice of methodology will be influenced by a variety of factors[14] but its selection should be the one which best represents the claim given the resources available.[15]

This has led to the development of numerous methodologies which can yield different results, even if the same methodology is used.[16] To add further complexity to the issue, there is inconsistency in the naming of the methodologies[17] but it is argued that the most thorough of these methodologies is time impact analysis. Time impact analysis can be used for prospective or retrospective analysis by analysing the effect of the delay on successive tasks based on the work achieved up to the point of the delay; however, this method of analysis is time consuming, costly and requires a certain standard of project records.[18] A variation of the time impact analysis is the window analysis which uses a system of "windows", usually weeks or months, to break the construction period into sections.[19] Under this method, the delay analysis is undertaken in the window and the revised schedule is used as the baseline for the subsequent window.[20] The reasons for the deviations from the dates in each window are then established.[21]

The findings from the analysis will be supported by a narrative which will attempt to explain the claimant's interpretation of what occurred on the project. Both the programme and the narrative provide forms of visual information which is preferred to oral information as it improves understanding and retention.[22] This allows a more informed decision to be made.

Challenge for delay analysts—representation

Case law stresses the need to "show that the claiming party was actually delayed by the factors of which it complains"[23] and leans towards the use of construction programmes, particularly the use of the critical path method,[24] to demonstrate this. Although accepted as a means to show cause and effect, delay programmes can be difficult to understand.[25] This was emphasised in the UK legal system by His Honour Judge Lloyd QC, who noted that an adjudicator required additional information to answer the questions he sought regarding a delay claim:

"This letter shows that the adjudicator was unable to make use (and, possibly, sense) of the material submitted on behalf of BB which included BB's 'as-built' programme and analysis."[26]

Furthermore, case law states that delay analysts must follow an objective approach and support their findings with factual evidence.[27] This can result in a claim becoming document intense which can prove challenging to understand in a limited time period. This is particularly true for individuals who were not involved in the project or who have limited practical construction experience, especially when it comes to interpreting technical construction drawings.[28] This is apparent in Hunte v E Bottomley & Sons where Lady Justice Arden states:

"Those who prepare bundles or skeleton arguments would do well to remember that a plan, map, diagram or photograph which is clear to people who are fully familiar with the case may well not be wholly clear to a judge coming to the case for the first time."[29]

In an attempt to combat these problems, the legal system is moving towards the use of technology to assist with the presentation of evidence.

Visual aids

Since the 1980s the entertainment industry has developed Computer Generated Imagery (CGI) for the internet, television, computer/video games and film. Its continual application has led to higher quality outputs and the availability of "off-the-shelf" software.[30] Despite the rapid uptake of CGI in the entertainment industry, the UK construction industry has been slow to adopt electronic information as a communication method. Developments towards Computer Aided Drafting/Design (CAD) were made in 1963[31]; however, the current level and use of CAD within the industry is extremely varied.[32] This varied uptake could be attributed to the uncoordinated nature of electronic information which must be interpreted by individuals; thus, little has changed from the traditional drawing board.[33]

Within the construction industry CGI is predominantly used in architectural design but it can be used to assist understanding and communication between interdisciplinary groups.[34] This benefit has been realised in legal proceedings and the use of CGE is rising as courts are becoming increasingly technologically sophisticated.[35]

CGI produces visualisations which represent information at a point in time and are used to enhance understanding.[36] Advancing visualisations through time generates a simulation which is classified as an animation if the user is unable to interact with it.[37] These forms of CGI can be used as CGE under the rubric of demonstrative evidence which has the overall aim of aiding understanding and clarifying facts for the judge and jury.[38] CGE can be used for a variety of purposes and its value as evidence will vary depending on the supporting documentation and how it is employed.[39] This can be classified with increasing probative value as descriptive, introductory, illustrative or evidential evidence.[40]

Cases such as the State of Connecticut v Alfred Swinton have used CGE and established the following authenticity requirements:

1. The computer equipment is accepted in the field as standard and competent and was in good working order.
2. Qualified computer operators were employed.
3. Proper procedures were followed in connection with the input and output of information.
4. A reliable software program was utilised.
5. The equipment was programmed and operated correctly.
6. The exhibit is properly identified as the output in question.[41]

The value of visualisations and animations have been investigated to assist the representation of disruption claims in the construction industry and found the use of a side by side comparison of as-planned versus as-built progress beneficial.[42] However, little research has been published on the use of CGE for delay claims. Acknowledgement has been given to the associated benefits of CGE in assisting the mitigation, representation and understanding of delay claims,[43] but this does not identify how CGE has been practically used and how it could be applied for delay claim purposes. This could be attributed to the limited technology associated with delay claims,[44] or because organisations do not want to publicise their competitive advantage. Furthermore, the dissemination of information is limited from a legal standpoint because CGE might only be used in some adjudications and arbitrations[45] where the decision or award is rarely/if ever reported.

Numerous software providers offer products which allow the virtual modelling of a construction project. This can be attributed to the growth of Building Information Modelling (BIM), a process of working which the UK Government has mandated a minimum level of use on all public sector construction projects by 2016. BIM is seen as a way of tackling the inefficiencies present in the industry through the process of recording and sharing a project's information throughout its lifecycle in electronic format.[46] This information is generated from, or linked to, a 3D virtual representation of the project which is produced using object based parametric modelling software. This software advances from 'traditional' CAD based lines and places objects with rules and parameters which determine both geometric and non-geometric properties and features.[47] The relationships and constraints between objects ensure realistic connections between elements and through synchronisation, a change to an object in one view will automatically update all other views and linked information. The benefits of synchronised information can be expanded to multiple dimensions which include 4D (time), 5D (cost) and 6D (FM).[48] If synchronised correctly, a change in any one of these views or dimension will instantly change all of the linked information for all other dimensions and will, therefore, report the most up-to-date information on the project. This could also be used retrospectively to assist the representation of delay claims[49] and could advance the construction dispute resolution system through the addition of new legal documents.[50]

METHOD

This research collects primary data through a case study. Case studies are a recognised research methodology, which explore complex problems in the context of their real-world environment.[51] Previous research has utilised case studies to demonstrate the application of CGE as supporting evidence[52] and this paper maintains that case studies are a suitable research methodology for the subject area.

Although the level of detail included in this paper has been limited to preserve the claims anonymity, the lessons learned can offer a "force of example" and may be transferable to other construction claims.[53]

Background to the case

Claim consultants were approached in 2010 by a sub-contractor (from here on known as the client) requesting expert delay analysis support on a construction project in the United Kingdom. The works, valued at several million pounds, included the design and construction of a reinforced concrete frame, internal stair cases and the provision for tower cranes, including the construction of the tower crane bases.

After investigation by delay analysts, critical delays were found in areas “A” and “B” for periods EOT1 and EOT2. The chosen delay analysis methodology was time impact analysis, which broke the total project duration into one month windows. This identified protective scaffolding and edge protection restrictions, which were the responsibility of others, as prominent delaying activities through stop-start relationships restricting the continuity of successive activities. Although not a complex site, the numerous on-going parallel tasks made it difficult to understand the cause and effect of these delay events. In an attempt to provide clarity on the claim, CGE was explored as a method of enhancing understanding.

2D simulation

A prototype 2D simulation of area “A” was created by a delay analyst using Microsoft Excel to determine whether simulations could offer additional clarity to the claim (Figure 1). The Excel simulation compares as-planned versus as-built progress side by side for the North, South, East and West faces of the building. Each floor comprises of the key sequencing activities which include: deck installed, scaffolding, edge protection, freedom to complete floor, and floor complete. Individual colours were applied to each activity for each level of the building but this has been adjusted to hatching for clarity in this publication. The progress of the works was automated by linking the visualisation to a bespoke Microsoft Excel construction programme.

The client saw a benefit of the simulation and decided to progress the concept into 4D which subsequently halted the development of the 2D simulation. As the claim consultants did not have expert skills in virtual modelling, an external organisation was employed to create a simulation to support the claim. Under the client’s request, communication was not allowed between the claim consultants and the virtual modelling organisation.

Figure 1 —Snapshot of a building’s progress from the 2D visualization

4D simulation

A 4D simulation of the client's work was created by a virtual modelling organisation using Synchro software. An open viewer of the software was made available which allowed the simulation to be viewed and analysed but no alterations could be made.

The simulation incorporated all of the client's work and colour coded the concrete superstructure levels (Figure 2). The visualisation was linked to an as-planned programme within the software to create the fourth dimension, time. Under the 4D simulation, delayed elements were highlighted in red, returning to the floor level colour once the object was installed. Due to the client's budget, the 4D simulation was not developed any further beyond the first revision.

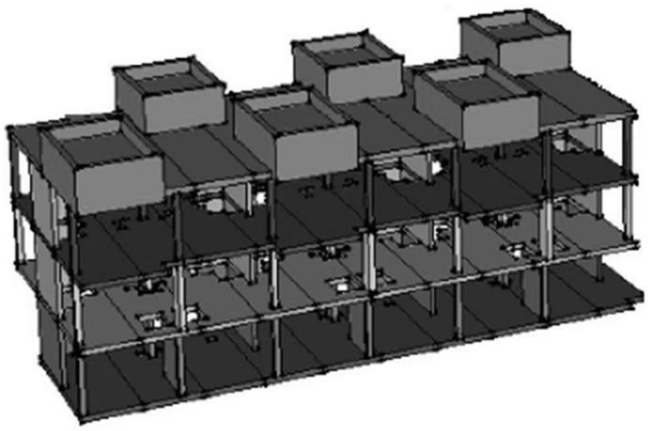

Figure 2 —Snapshot of a building from the 4D visualisation

ANALYSIS

2D simulation

Benefits

The 2D simulation provides an easy to understand representation of delays. The simulation colour codes five elements of sequencing works which make it clear to understand what is in delay and the effect on the rest of the project. The simulation shows as-planned versus as-built progress side by side, as recommended by Pickavance,[54] for all faces of the project which simplifies the understanding of how the works progressed in an area and the impact of delay. In order to assist the understanding of the as-planned and as-built progress, the simulation can be paused, or a specific date selected, to provide a visual comparison of planned and actual progress at a point in time.

Limitations

Some of the limitations associated with the 2D simulation could have been tackled if the simulation had been continually developed; others are inherent in the software.

If additional time and resources were available to develop the 2D simulation, it could have included additional activities involved in constructing the project. In its current state, the 2D simulation demonstrates the sequencing of works to complete each horizontal level, it does not take into account the erection of columns or striking of formwork. Although simple to demonstrate in the software, the records available from the client did not allow for its incorporation at the time it was produced.

Limitations in the software exist as it could not be linked to a construction programme with logic, a recognised tool for successful delay claim resolution. Duplication of effort was, therefore, required to ensure an accurate construction programme was created which coordinated with Microsoft Excel.

A further limitation is that the simulation is not eye-catching or to scale. The simulation does not represent the site layout or space available between areas, which may give a misconception of the amount of work undertaken and incomplete. If the site has not been visited by the viewer, it would not assist with understanding the size and layout of the works which is identified as a challenge for some individuals. Furthermore, the simulation only shows four sides of one building and not the whole project.

Although this may be suitable for a single tower block, if multiple buildings were included in one view, it may become difficult to understand.

Possible improvements

The 2D simulation was developed in a Microsoft Office software package which makes it extremely interoperable. The simulation does not utilise this and the possibility exists to add annotations and link documents, such as the narrative, delay programme or photographs, to the simulation to provide evidence and clarity on the key requirements of causation, liability and quantum.

While the 2D simulation provides clarity on the construction delays, its visual impact is limited through the software capabilities. Therefore, additional software could be used to make it more visually appealing.

4D simulation

Benefits

The 4D simulation provides an accurate, detailed, virtual representation of the construction works which were undertaken by the client. This allows the viewer to clearly understand the construction site without ever having to visit. With the ability to pan around the simulation it is possible to assess a specific building or element from any desired angle. When linked to the construction programme, it allows the viewer to see the construction of the building virtually, without having to understand the construction programme in detail. Thus, it helps overcome some of the challenges which are faced when trying to understand delay.

Limitations

Despite the benefits realised in the 4D simulation, it was not useful in “showing” the cause and effect relationship of the delay event, a key requirement identified in the case law.

The main limitation of the 4D simulation is that it does not represent as-planned versus as-built progress side by side. Instead, the as-planned programme is linked to the visual representation of the works and the elements in delay are coloured red. This is not a clear method of representing delay because the programme is not shown and the works appear to progress as-planned, bar the different colour. The red colour only indicates that an object was late to start and, therefore, does not distinguish if it the activity is absorbing float, is a delay to progress or a delay to completion. Furthermore, the 4D simulation does not clearly demonstrate the stop-start relationship of the works and lacks impact.

Given the restrictions of the software, annotations, links and photographs may not easily be included to assist with understanding. Despite the ability to pan around the simulation, the single view of the project did not show the effect of scaffolding restrictions for all faces of a building. Furthermore, the simulation only represented the finished floor and column elements, it did not break down the sequencing of delay events or include any resources, such as scaffolding. These are features supported by the software which would have assisted understanding the cause and effect of delays.

Possible improvements

The limitations of the 4D simulation could have been mitigated if direct contact was allowed between the claim consultants and the virtual modelling organisation. The reason why communication was restricted is unknown but it is assumed to be due to confidentiality reasons given the sensitive nature of the case. It is thought that the individuals creating the simulation had no experience of delay analysis. If direct communication was allowed, the two teams would have been able to assist each other and this may have solved the problem of not having as-planned versus as-built progress side by side. This function is not available in all software packages; however, the software used in this particular case does have this function. Additionally, the software could have been used to generate multiple angles or snapshots of the project for an exact moment in time. This would allow the impact of the delay to be represented for the whole project at a point in time.

The 4D simulation could be further enhanced by attaching or linking information as the required supporting evidence for the claim. If this is not an available feature in the software, additional software could be employed, such as a voice recorded description of the analysis which plays over the simulation.

RECOMMENDATIONS

Cost benefit analysis

A cost benefit analysis should be undertaken to determine whether CGE will add value to the claim, if not, it should not be created. If CGE is deemed beneficial, the added value should be determined and an appropriate budget set to avoid excessive and disproportionate legal costs which are common in civil litigation.[55] The budget should take into account the level of detail required for the CGE to support the claim and should allow for the exhibit to be refined through multiple revisions.

Ideally, a claim should be resolved at the earliest opportunity to stop it escalating.56 Therefore, CGE could be employed at the initial claim in an attempt to reduce the likelihood of it developing. This may, therefore, require a CGE of lower probative value.

With more projects likely to have virtual models created due to the increasing uptake of BIM, it should become cheaper and easier to refine the models which were developed to manage the project to support a construction claim.

Determine what's necessary

The purpose of CGE is to assist the understanding of complex material; therefore, the exhibit should reflect what is being discussed in its simplest and clearest form.

Software and expertise

It is easy to buy into specialist software to produce CGE; however, this will create additional costs, require training and could add little, or no, value to the claim. Knowing the capabilities of readily available software, such a Microsoft Excel, and the skills of the in-house team can be beneficial when creating a CGE for a construction claim.

Simple can be effective

Regardless of the software employed, the CGE must have impact and engage the viewer; however, it is important that it does not distract from critical information.[57]

To effectively convey the findings of the delay analysis, only the information relevant to the claim should be included in the exhibit and that of significant importance should be emphasised without appearing patronising. If CGE is used, it is advised to not exceed 20 minutes in duration and could be broken up by 'energy shifts', such as oral discussion to retain the viewer's attention.[58] Specific delay events or each window of analysis could be represented to keep within the duration.

Given the difficulty of representing the whole of the construction site in one view, the cause and effect for specific areas of the site could be simulated. This could be represented as multiple views on one screen or divided into individual simulations with a concluding simulation to show their collective impact. This could also be used break up the duration of the CGE.

What is to be represented and how it is to be used will determine the level of detail to be included in the exhibit. Schematics may be adequate to introduce the construction site; however, detailed technical visualisations may be required as evidential evidence to demonstrate design changes. Key resources used in events which cause delay should be displayed but unnecessary detail should be avoided as it can incur additional costs and may distract the viewer.

Colours are an effective way of conveying meaning if used correctly but overuse can become distracting. The same applies to the incorporation of additional information to a simulation, such as voiceover, photographs, annotations and links. Although these may provide clarity, too much may become distracting, confusing and lose impact.

Side by side comparison with timeline

If CGE is used to support construction delay claims, a side by side comparison of as-planned and as-built progress is highly recommended. This direct visual comparison will generate impact and provide clarity on the effect of delay events.

If a simulation or animation is used, the construction programme driving it should be displayed to relate the construction to a point in time. The construction programme should be factual, visually appealing, easy to follow and readable.[59] The delay analysis programme may be too complex; therefore, a simplified timeline may need to be created.

Communication

To effectively use CGE to represent the delay analysis, communication between the delay analysts and the virtual modelling organisation is recommended. It is unfair to expect a virtual modelling organisation to understand a complex delay claim and accurately demonstrate it in a virtual environment with no support from a delay analyst. Neither is it fair to expect a delay analyst to be able to virtually model a construction site. Ideally, a role would be created for an individual who has an appreciation of both disciplines and can advise on the above points. If this is not feasible, a constant clear line of communication between both teams is essential.

Information which may not traditionally be requested by delay analysts, such as technical drawings, may be required to develop the CGE. It is recommended that this information is requested early on to assist with the development of the CGE; however, it is acknowledged that obtaining relevant information is a separate challenge for delay analysts.[60]

CONCLUSION AND FUTURE WORK

If used correctly, CGE can assist with the representation of construction delay claims. The use of CGE for this purpose is likely to rise given the construction industry's move towards BIM and the increasing use of technology in the courts. However, the case study demonstrates that CGE is not being successfully employed to assist with construction delay claims.

The proposed recommendations for improvement are not exhaustive and while some of these recommendations may appear obvious, the case study demonstrates that they are not always employed and may not even be considered. This could be due to the limited published research in the area and/or the unfamiliarity organisations have with using CGE to support a construction claim. Therefore, it is hoped that these recommendations will act as a form of guidance and help to improve and promote the future application of CGE for delay claim purposes.

Further research is required to test the recommendations and understand how they could be transferred to assist the use of CGE on other types of construction claims. This, along with the potential of utilising BIM to assist with construction delay claims, is being investigated as part of an Engineering Doctorate (EngD).

REFERENCES

[1] CIOB, Managing the Risk of Delayed Completion in the 21st Century (CIOB, 2008). NAO, Modernising Construction. Report by the Controller and Auditor General (The Stationery Office, 2001), HC Paper No.87 (Session 2000/01).

[2] Kumaraswamy, M., "Conflicts, Claims and Disputes in Construction" (1997) 4(2) Engineering, Construction and Architectural Management, 95.

[3] EC Harris, Global Construction Disputes: A Longer Resolution (EC Harris, 2013).

[4] Love, P., Davis, P., Ellis, J. and Cheung, S., "Dispute Causation: Identification of Pathogenic Influences in Construction" (2010) 17(4) Engineering, Construction and Architectural Management, 404

[5] Keane, P. and Caletka, A., Delay Analysis in Construction Contracts (West Sussex: Wiley-Blackwell, 2008). Conlin, J. and Retik, A., "The Applicability of Project Management Software and Advanced IT Techniques in Construction Delays Mitigation" (1997) 15(2) International Journal of Project Management, 107.

[6] Cooper, M., "The Use of Demonstrative Exhibits at Trial: Practitioner's Guide" (1999) 34(3) Tulsa Law Journal. Schofield, D., "Playing with Evidence: Using Video Games in the Courtroom" (2011) 2 Entertainment Computing, 47.

[7] Pickavance, K., Delay and Disruption in Construction Contracts, 4th edn (London: Sweet & Maxwell, 2010).

[8] Fenwick Elliott. Dictionary of Construction Terms. Edited by S. Tolson, J. Glover and S. Sinclair (London: Informa Law, 2012).

[9] Farrow, T., “Delay Analysis — Methodology and Mythology”. A paper based on a talk given to a meeting of the Society of Construction Law in Manchester on November 6, 2001.

[10] SCL, “Delay and Disruption Protocol” Society of Construction Law (2002).

[11] Trauner, T., Manginelli, W., Lowe, J., Nagata, M. and Furniss, B., Construction Delays: Understanding them Clearly, Analysing them Correctly, 2nd edn (London: Elsevier, 2009).

[12] Williams, T., Ackermann, F., Eden, C., “Structuring a Delay and Disruption Claim: An Application of Cause-mapping and System Dynamics” (2003) 148 European Journal of Operational Research, 192.

[13] Haidar, A. and Barnes, P., Delay and Disruption Claims in Construction: A Practical Approach (London: ICE publishing, 2011).

[14] Braimah, N. and Ndekugri, I., “Factors Influencing the Selection of Delay Analysis Methodologies” (2008) 26 International Journal of Project Management, 789.

[15] Bubshait, A. and Cunningham, M., “Comparison of Delay Analysis Methodologies” (1998) Journal of Construction Engineering and Management, 315.

[16] Keane and Caletka, Delay Analysis in Construction Contracts (2008).

[17] AACE. Forensic Schedule Analysis. TCM Framework: 6.4—Forensic Performance Assessment. AACE International Recommended Practice No. 29R-03 (2011).

[18] SCL, “Delay and Disruption Protocol” Society of Construction Law (2002).

[19] Arditi, D. and Pattanakitchamroon, T., “Selecting a Delay Analysis Method in Resolving Construction Claims” (2006) 24 International Journal of Project Management, 145.

[20] Hegazy, T. and Zhang, K., “Daily Windows Delay Analysis” (2005) 131 Journal of Construction Engineering and Management, 505.

[21] Whatley, P., The Project Planning Handbook (Leicester: Troubador Publishing, 2014).

[22] Keane and Caletka, Delay Analysis in Construction Contracts (2008).

[23] Cleveland Bridge UK Ltd v Severfield Rowen Structures Ltd [2012] EWHC 3562.

[24] Alstom Ltd v Yokogawa Australia Pty (No.7) [2012] SASC 49.

[25] Kumaraswamy, M., and Yogeswaran, K. “Substantion and Assessment of Claims for Extensions of Time” (2003) 21 International Journal of Project Management, 27.

[26] Balfour Beatty Construction v Lambeth London Borough Council [2002] EWHC 597.

[27] Walter Lilly & Company Ltd v Mackay & Anor [2012] EWHC 1773.

[28] Dziurawiec, S. and Deregowski, J., “Construction Errors as Key to Perceptual Difficulties Encountered in Reading Technical Drawings” (1986) 29(10) Ergonomics, 1203.

[29] Hunte v E Bottomley & Sons [2007] EWCA Civ 1168.

[30] Parent, R., Computer Animation Algorithms & Techniques, 3rd edn (USA: Elsevier).

[31] Tizzard, A., Introduction to Computer-aided Engineering (McGraw-Hill, 1994).

[32] NBS, National BIM Report (NBS, 2012).

[33] Sacks, R., Eastman, C., Lee, G., “Parametric 3D Modeling in Building Construction with Examples from Precast Concrete” (2004) 13 Automation in Construction, 291.

[34] Bouchlaghem, D., Shang, H., Whyte, J. and Ganah, A., “Visualisation in Architecture, Engineering and Construction (AEC)” (2005) 14 Automation in Construction, 287.

[35] Narayanan, A. and Hibbin, S., “Can Animations be Safely used in Court?” (2001) 9 Artificial Intelligence and Law, 271.

[36] Card, J., Mackinlay, B. and Shneiderman, B., Readings in Information Visualization: Using Vision to Think (San Francisco: USA, Morgan Kaufmann, 1999).

[37] Macal, C., "Guest Editor's Introduction — Special Issue" (2001) September-October Simulation and Visualization, 90.

[38] Norris, G. and Reeves, H., "The Influence of Vehicle Model and Colour on Assessments of Speed and Culpability: the Case for (and Against) Computer Generated Exhibits (CGE)" (2012) 26(1) International Review of Law, Computers & Technology, 37.

[39] Schofield, D., Hussin, N. and Shalaby, M., "A Methodology for the Evidential Analysis of Computer-Generated Animation (CGA)", Proceedings of the Ninth International Conference on Information Visualisation (IV'05) (2005).

[40] Burr, A. and Pickavance, K., "The Use of Visualisations in Case Presentation and Evidence" (2010) 26(1) Const. L.J. 3.

[41] State of Connecticut v Alfred Swinton [2004] SC 16548.

[42] Pickavance, K., "Using Advanced Forensic Animations to Resolve Complex Disruption Claims" Society of Construction Law (2007), a paper presented to the inaugural meeting of the Four Counties branch of the Society of Construction Law in Milton Keynes, March 22, 2007.

[43] Conlin, J. and Retik, A., "The Applicability of Project Management Software and Advanced IT Techniques in Construction Delays Mitigation" (1997) 15(2) International Journal of Project Management, 107. Keane and Caletka, Delay Analysis in Construction Contracts (2008).

[44] Vidogah, W. and Ndekugri, I., "A Review of the Role of Information Technology in Construction Claims Management" (1998) 35 Computers in Industry, 77.

[45] Pickavance, Delay and Disruption in Construction Contracts, (London, 2010).

[46] Cabinet Office. Government Construction Strategy, May 2011.

[47] Eastman, C., Teicholz, P., Sacks, R. and Liston, K., BIM Handbook: A guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, 2nd edn, (Hoboken, New Jersey: John Wiley & Sons, 2011).

[48] RIBA, BIM Overlay to the RIBA Outline Plan of Work (London: RIBA Publishing, 2012).

[49] Gibbs, D., Emmitt, S., Ruikar, K. and Lord, W., "An Investigation into whether Building Information Modelling (BIM) can Assist with Construction Delay Claims" (2013) 2(1) International Journal of 3-D Information Modeling,45.

[50] Greenwald, N., "A Creative Proposal for Dispute Systems Design for Construction Projects Employing BIM" (2013). Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 5, 2–5.

[51] Yin, R., "Validity and Generalization in Future Case Study Evaluations" (2013) 19(3) Evaluation, 321.

[52] Schofield, "Playing with Evidence: Using Video Games in the Courtroom" (2011) 2 Entertainment Computing, 47; Pickavance, "Using Advanced Forensic Animations to Resolve Complex Disruption Claims" Society of Construction Law (2007), a paper presented to the inaugural meeting of the Four Counties branch of the Society of Construction Law in Milton Keynes, March 22, 2007.

[53] Flyvberg, B., "Five Misunderstandings about Case-Study Research" (2006) 12(2) Qualitative Inquiry 219.

[54] Pickavance, K., "Using Advanced Forensic Animations to Resolve Complex Disruption Claims" Society of Construction Law (2007), a paper presented to the inaugural meeting of the Four Counties branch of the Society of Construction Law in Milton Keynes, March 22, 2007.

[55] Jackson, R., Review of Civil Litigation Costs (The Stationery Office, 2010).

[56] Keane and Caletka, Delay Analysis in Construction Contracts (2008).

[57] Cooper, M., "The Use of Demonstrative Exhibits at Trial: Practitioner's Guide" (1999) 34(3) Tulsa Law Journal.

[58] Boyle, R., "Applying Learning-styles Theory in the Workplace: How to Maximise Learning-styles Strengths to Improve Work Performance in Law Practice" (2008) Legal Studies Research Paper Series: St John's University, Paper #08-0112.

[59] Keane and Caletka, Delay Analysis in Construction Contracts (2008).

[60] Gibbs, D., Emmitt, S., Ruikar, K. and Lord, W., "An Investigation into whether Building Information Modelling (BIM) can Assist with Construction Delay Claims" (2013) 2(1) International Journal of 3-D Information Modeling, 45.

APPENDIX E JOURNAL PAPER 5

Gibbs, D., Lord, W., Emmitt, S. and Ruikar, K. (2016). Interactive Exhibit to Assist with Understanding Project delays. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, pp.04516008-1-04516008-12.

Interactive Exhibit to Assist with Understanding Project Delays

ABSTRACT

Time, a dynamic concept, can be difficult to understand in static form. As a consequence, the proactive management and retrospective analysis of delays on construction projects can prove challenging using conventional methods. This can result in time overruns and the rejection of valid delay claims that can develop into dispute if they are not resolved. Disputes have a negative effect on the construction industry, but their occurrence, value, and duration are rising. This research aims to reduce the likelihood and severity of common delay disputes by providing a solution that aims to (1) assist with the proactive management of delays; and (2) improve the presentation of delay claim information. A detailed background study was undertaken that identified technological opportunities and modes of presentation as potential ways of overcoming the challenges associated with managing and analyzing delays. Two stages of assessment were then undertaken to determine the suitability and application of these findings. The first stage used a workshop with 50 construction adjudicators to determine the appropriateness of modes of presentation in assisting construction claims. The second stage developed the workshop findings with previous research and integrated modes of presentation with delay analysis. The output was an interactive exhibit that was assessed through a simulation based on case study data. The interactive exhibit is intended to support, not replace, traditional methods of delay analysis; however, the solution has difficulties with technology as well as the challenge of creating a holistic tool for both proactive management and retrospective analysis. It is perceived that the interactive exhibit will add most value to the resolution of construction delay claims, but that further investigation is required to validate the proposed concept before it is used in practice.

AUTHOR KEYWORDS

Four dimensional (4D); Building information modeling (BIM); Claim; Delay; Dispute; Evidence; Extension of time; Modes of presentation; Proactive control; VARK.

INTRODUCTION

More than 60% of complex construction projects are not delivered by their due date (CIOB 2008), and this can lead to cost overruns, benefit shortfalls (Flyvberg 2014), and disputes. Disputes occur after a claim is rejected and generate direct and indirect costs for the parties involved (Love et al. 2010). Despite the negative consequences, the number of disputes in the construction industry is expected to rise (NBS 2015), and two of the common causes include (Arcadis 2015)

- Failure to make interim awards on extensions of time and compensation; and
- Poorly drafted or incomplete and unsubstantiated claims.

This research aims to reduce the likelihood and severity of disputes by providing a holistic solution to their common causes. This includes

- Assisting with the proactive management of delays so appropriate control action can be taken and interim awards of time extensions of can be granted; and
- Improving the presentation of delay claims so they are better understood and can be settled before external support is required.

To provide context for the research, a detailed study into delays was undertaken. The study identified the challenges of understanding delays and how technological opportunities and modes of presentation can assist the current legal environment. Because a link between modes of presentation and delay analysis is not present in the literature, two stages of assessment were undertaken to determine the suitability and application of the proposed concept. The first stage determined the appropriateness of using different modes of presentation on construction claims by collecting data from a workshop with 50 industry experts. The second stage developed the findings of the workshop and previous research (Gibbs et al. 2014) to produce a concept that integrates modes of presentation with delay analysis. The output is an interactive exhibit that is assessed through a simulation using case study data. The research findings show that modes of presentation can be integrated with delay analysis and that an interactive exhibit can assist with understanding delay. The proposed concept is intended to support, not replace, traditional methods of delay analysis, and it is recommended that additional stages of assessment be undertaken before the concept is used in practice.

BACKGROUND

Managing Time and Analyzing Delay

The term delay can be defined as the noncompletion of works by a date agreed in the construction contract (Fenwick Elliott 2012). A delay event can occur for a wide range of reasons (Ramanathan et al. 2012) and can affect project progress or project completion (SCL 2002). A construction program, also referred to as a construction schedule, can be used to manage time on a project and should consider contractual compliance, logic, duration, development, and components (Moosavi and Moselhi 2014). It is recommended that the construction program be produced according to the critical path method (CIOB 2011), which uses activity durations and logical relationships to mathematically calculate the shortest possible time to complete a project (Kelley 1961). Activities that are delayed on the critical path extend project duration, and there may be parallel, or near critical, paths on a project. Therefore, because of the amount of change a project will encounter, it is likely that the critical activities will alter as the project progresses (Whatley 2014).

Good project management recommends that the construction program be continually updated and revised as more accurate and detailed information becomes available, which includes impacting change events into the program (CIOB 2011). Delay can still occur if this good practice is followed, but the proactive approach should allow the effect of change to be realized close to when the event arose. Therefore, appropriate control action can be taken or prospective claims can be submitted based on the findings of the analysis. However, many projects do not follow this good practice, and the processes and tools they adopt for proactive management may not produce the information required for retrospective analysis (Scott 1990). As a consequence, if the effect of a change event is not analyzed contemporaneously, a retrospective delay analysis may be required.

A delay analysis forensically investigates the issues that have caused a project to run late (Farrow 2001). There is no single way to prove delays, so there is no standard way of undertaking a delay analysis (Tieder 2009). This has led to the development of numerous methodologies that can yield different results, even if the same methodology is used (Braimah 2013).

The legal system leans toward the use of construction programs, particularly the use of the critical path method, for delay analysis (Bayraktar et al. 2012). A plethora of titles exist for types of delay analysis (AACE 2011), and there is no preferred type; however, some recognized analysis methods can be categorized (SCL 2015):

- As-planned versus as-built;
- Impacted as-planned;
- Collapsed as-built;
- Longest path analysis; and
- Time impact analysis.

The benefits and limitations of these methodologies are discussed in the literature (Arditi and Pattanakitchamroon 2006), but the chosen methodology will be influenced by a variety of factors, most notably the factual material available (Braimah and Ndekugri 2008). Not all of the methods are recognized as appropriate for both proactive management and retrospective analysis, so adjustments for delay type scrutiny, excusable delays, and treatment of concurrent delays may need to be made depending on whether the method is classified as rough, simple, or sophisticated (Ng et al. 2004). This classification can influence how delay is communicated.

The time impact analysis is identified as a sophisticated methodology that can be used for both proactive management and retrospective analysis of delay (CIOB 2011). This methodology involves the following activities (SCL 2002):

- Bringing the program up to date before the delay event occurs and correcting incorrect logic and durations;
- Modifying the program to reflect achievable plans and any recovery action to be taken;
- Impacting the delay event into the program; and
- Reviewing the impact of the delay event on the project completion date.

The time impact analysis is best applied prospectively, but it can also be used for retrospective analysis. However, this methodology is not without its shortcomings, and it is recommended that the findings be compared with as-built information to ensure the integrity of the analysis (Whatley 2014).

To make complex analyses easier to understand, windows (sometimes called time slices) can be applied to any delay analysis method. This involves dividing the program into logical segments and analyzing the impact of delay in each segment (Pickavance 2010). However, even if this approach is used, the claim may still not be understood or agreed on; thus, it can be rejected and potentially develop into a dispute.

Claims and Disputes

The number of disputes in the construction industry are expected to rise (NBS 2015), and the global average construction dispute costs US$51.1 million, lasts 13.2 months (Arcadis 2015), and generates indirect costs of lost productivity, stress and fatigue, loss of future work, reduced profit, and tarnished reputation (Love et al. 2010). A dispute occurs when a claim cannot be resolved; however, because change is inevitable on any project, some claims are an inherent and necessary part of construction (Kumaraswamy 1997). Therefore, claims should not be judged emotively or as an indication of project failure (CRC 2007). Instead, they should be addressed appropriately to avoid the potential of dispute.

Claim Requirements

A claim is intended to return the party affected by a change to the position they would have been in if the change had not occurred (Robinson v. Harman). Unless designated in the contract, a claim is required to be proven to receive damages, and the burden of proof lies with the party making the assertion. A claim should prove breach, causality, responsibility, and quantum (Williams et al. 2003) that is not too remote (Hadley v. Baxendale), and be presented in its clearest form (National Museums and Galleries on Merseyside Board of Trustees v. AEW Architects and Designers Ltd.). It will be judged on the balance of probabilities, which is that an event is more likely than not to have occurred, and can be swayed by the standard of evidence provided (Haidar and Barnes 2011). This will depend on the available facts and how they are presented (Gibbs et al. 2013), with preference given to neutral, contemporaneous records (Kangari 1995). The recoverable damages will be subject to remoteness and how the delay is categorized, which is dependent on the contract and the claiming party (Fig. 1).

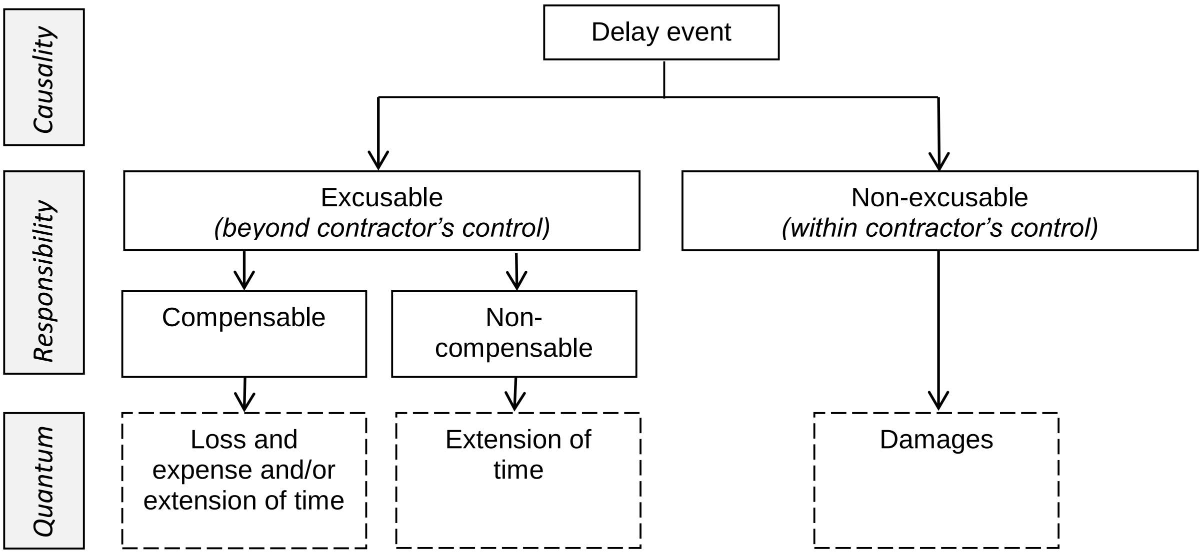

Fig 1. Generalised interpretation of the categories of delay (adapted from Trauner, 2009)

Delay Claim Challenges

Previous research identified two challenges associated with analyzing delay: the retrieval of information to perform the analysis and the communication of the findings (Gibbs et al. 2013). Attempts to address the retrieval of delay claim information are presented in the literature (Alkass et al. 1995), and developments in electronic document management systems should, in some way, assist with addressing this challenge. However, little research is published that investigates how to improve communication and understanding of the cause and effect of delay to support proactive decision making and retrospective analysis.

Although it may be simple for a claim to originate, communicating and agreement on the effect of change on a project can be difficult. This is because a change to a single item has a ripple effect on other, often complex and interrelated work activities (CIRIA 2001). Therefore, the sum of individual changes does not necessarily equal the overall change to a project (Williams et al. 1995).

Conventionally, construction delay claims are paper-intensive and consist of a claim report narrative, construction programs, and supporting evidence. However, these modes of communication are not always appropriate because time, a dynamic concept, can be difficult to understand in a static format (Balfour Beatty Construction v. Lambeth London Borough Council). In the current process, users must conceptually associate two-dimensional (2D) drawings with the related project tasks to form an image of what occurred on the project (Koo and Fischer 2000). Interpreting 2D technical drawings can be challenging (Girbacia 2012), especially for individuals with limited practical experience of the project (Hunte v. E Bottomley & Sons), and this can make judging the effect of change events difficult. Therefore, although it may be clear that damage has been suffered as a result of delay, this can be extremely difficult and expensive to prove (Clydebank Engineering Co. v. Don Jose Yzquierdo y Castaneda). In an attempt to overcome these challenges, the courts have started to use technology (Narayanan and Hibbin 2001; Feigenson and Spiesel 2011; Schofield 2011).

Use of Technology in the Legal Sector

The legal sector tends to be risk averse, so any technology that is adopted by legal service providers is required to go through rigorous analysis and review to ensure that it is correctly used and fit for purpose. Client demands, competitive pressure, and the recession have prompted law firms to increase information technology (IT) use, but investment in technology by the legal sector still remains lower than it is in other industries (LSN 2015).

In an attempt to improve efficiency, the United Kingdom criminal justice system is going through a process of digitization. The aim is to reduce the heavy reliance on paper, which contributes to fragmentation and wasted time, and replace it with digital case files, digital courtrooms, and a single information management system (MoJ 2013). To support this initiative, screens and equipment are being installed in courts. This will provide the opportunity for incourt digital evidence such as video links with witnesses and the clear display of evidence directly to the court from an advocate's personal laptop or handheld device (MoJ 2014). This opens up numerous opportunities for presenting evidence.

Opportunities

Further investigation was undertaken to determine how the technological capabilities of the courts can be harnessed to improve the communication of delay events. To develop a feasible solution, appreciation was given to the digital tools and processes that are becoming commonly used on construction projects [building information modeling (BIM) and four-dimensional (4D) modeling]. The ability to use the available digital outputs as evidence in the highest legal setting, the courtroom, was explored (computer-generated exhibits), as were the opportunity to enhance understanding through technology (interactive videos) and the science behind communication (modes of presentation).

4D Modeling

Four-dimensional modeling is the process of linking a construction program to a three-dimensional (3D) virtual model to produce a sequence of the construction work (RIBA 2012). Virtual 3D models are not always produced for construction projects, and their absence has restricted the uptake of 4D modeling. However, access to object-oriented 3D virtual models has increased following the uptake of BIM on international construction projects (NBS 2014). This has provided a platform for 4D modeling and the opportunity to harness recognizable benefits, most notably in the planning and construction stages when information needs to be communicated to individuals with a lack of site-related knowledge (Mahalingam et al. 2010). Using this approach, individuals no longer have to imagine and interpret the activity sequence in their mind; instead, they are able to view a fact-driven 3D construction sequence using a single medium (Koo and Fischer 2000). Coupled with the appropriate skill set, 4D modeling can be used for effective communication to foster productive discussions for proactive management or in the early stages of different forms of alternative dispute resolution (Wing 2016). However, although BIM and 4D modeling can assist with reducing the likelihood and severity of some disputes, they do not eradicate disputes within the industry. The new processes of working and ways of communicating information can unveil different forms of dispute (Gibbs et al. 2015; Olatunji 2016).

Computer-Generated Exhibits

Demonstrative evidence, in the form of computer-generated exhibits (CGEs), has proven advantageous in the courtroom (Cooper 1999). This includes videos of virtual construction sequences, which have been identified as a way of assisting the mitigation, representation, and understanding of construction delays (Conlin and Retik 1997). Such exhibits can be classified in increasing probative value as (Burr and Pickavance 2010)

- Descriptive: not factually driven but story-based, on facts;
- Introductory: summary of principal issues, but can omit parts;
- Illustrative: description of something that cannot normally be seen; and
- Evidential: a different way of demonstrating primary evidence.

However, construction delays have experienced little advancement in technology (Vidogah and Ndekugri 1998) and only a small amount of research discusses the practical application of CGEs for construction claims (Pickavance 2007). To avoid affecting the admissibility of CGEs as evidence, emotive content such as that created by manipulating camera angles and adding special effects should be avoided (Schofield 2011). Further research into this field is required (Feigenson and Dunn 2003), but in an attempt to overcome these challenges and to encourage CGE use, recommendations on the creation of CGEs for the proactive control and retrospective analysis of delay have been published (Gibbs et al. 2014). The suggestions include

- Performing a cost-benefit analysis to determine the value of the CGE to the claim;
- Accurately demonstrating the delay in its clearest form;
- Producing a side-by-side comparison of as-planned and as-built CGEs with timeline; and
- Ensuring communication between the creators of the program and the virtual modeling organization.

Interactive Videos

Although visualizations can increase intuitive perception, data can be better evaluated and alternatives analyzed if the viewer is able to interact (Pensa et al. 2014). This has given rise to interactive videos, which place motion-tracking hotspots, or tags, on an item in the video. The tags remain fixed on the item as the video progresses, and when viewers click a tag, they can access more information about an item and influence the flow of the video (Stenzler and Eckert 1996). This concept has been employed by the advertising industry, but its benefits can assist with education because it improves understanding through the incorporation of different modes of presentation in one medium.

Modes of Presentation

When information is processed, three types of memory are required for meaningful learning to take place. Sensory memory briefly stores sights and sounds and transfers information to the working memory. Working memory is limited and so temporarily stores information to be organized; this is where viewers hold their attention (Clark and Mayer 2008). The new information is then integrated with existing knowledge to form long-term memory and understanding (Mayer 2009).

The ability to integrate information can depend on how the material is communicated. VARK modes of presentation identify that individuals learn in different ways and have a preference for one of the following (the first letters of which make up the VARK acronym) (Fleming and Mills 1992; Leite et al. 2010):

- Visual: graphical and symbolic information;
- Aural: heard information;
- Read/write: printed information; and
- Kinesthetic: information acquired through application and multisensory experiences.

Preference for a mode of presentation is not specific to a certain type of job. For example, lawyers, who might be perceived to learn in read/write mode, actually have diverse learning styles (Boyle 2012). A combination of presentation modes may be advantageous to some individuals (Mayer and Anderson 1991; Fleming 1995) while improving the satisfaction of the task (Sung and Mayer 2012). However, in some instances individuals can report fragmented or even no learning because the working memory is overloaded with irrelevant information (Mayer et al. 2001). To combat this, regular pauses are recommended (Spanjers et al. 2012) and rules and guidelines have been developed for the presentation of and interaction with information (Baldonado and Kuchinksy 2000).

METHODOLOGY

This research investigates if the communication of project delays can be improved by incorporating different modes of presentation into available technology. Because no literature was found that identifies whether and how VARK modes of presentation can assist with understanding project delays, two stages of assessment were undertaken. The first stage tested the appropriateness of integrating VARK modes of presentation with delay analysis through a workshop with industry experts. The second stage demonstrated how these findings can be applied in the industry through a simulation.

Workshop

Expert opinion was sought to determine the feasibility of using the VARK modes of presentation to improve understanding of project delays (Wieringa 2014). This was achieved by collecting data in a workshop. Workshops allow a researcher to engage with individuals who are concerned about a topic in order to investigate a problem and find a possible solution (Fisher 2004). To determine the appropriateness of integrating modes of presentation with delay analysis, a 30-minute workshop was held with 50 practicing Royal Institute of Chartered Surveyors (RICS) adjudicators. Adjudicators were chosen because they regularly encounter the challenge of understanding construction claim information and, although their appointment indicates a dispute, their experience offers useful insights into how construction projects are managed, the standard of claim information provided by the industry, and the level of evidence required to support a claim.

The 50 RICS adjudicators were presented with background information on the challenge of representing construction delay information, the rise and perceived benefits of CGEs, and details about learning styles. For the purpose of the workshop, CGE was described as the use of a computer to generate static or dynamic imagery of tangible construction operations, and excluded construction programs, photographs, and videos. An example CGE was presented to demonstrate its use to support a claim (Fig. 2). This example used graphs, 2D site layout, and animation to show the process of casting, shipping, storing, and installing concrete segments for construction of a viaduct. The VARK visual components demonstrated that the works were out of sequence and the impact that this had on the project. Aspects of VARK kinesthetic learning were incorporated into the CGE as the user became able to increase speed, filter information, and access further information through interaction.

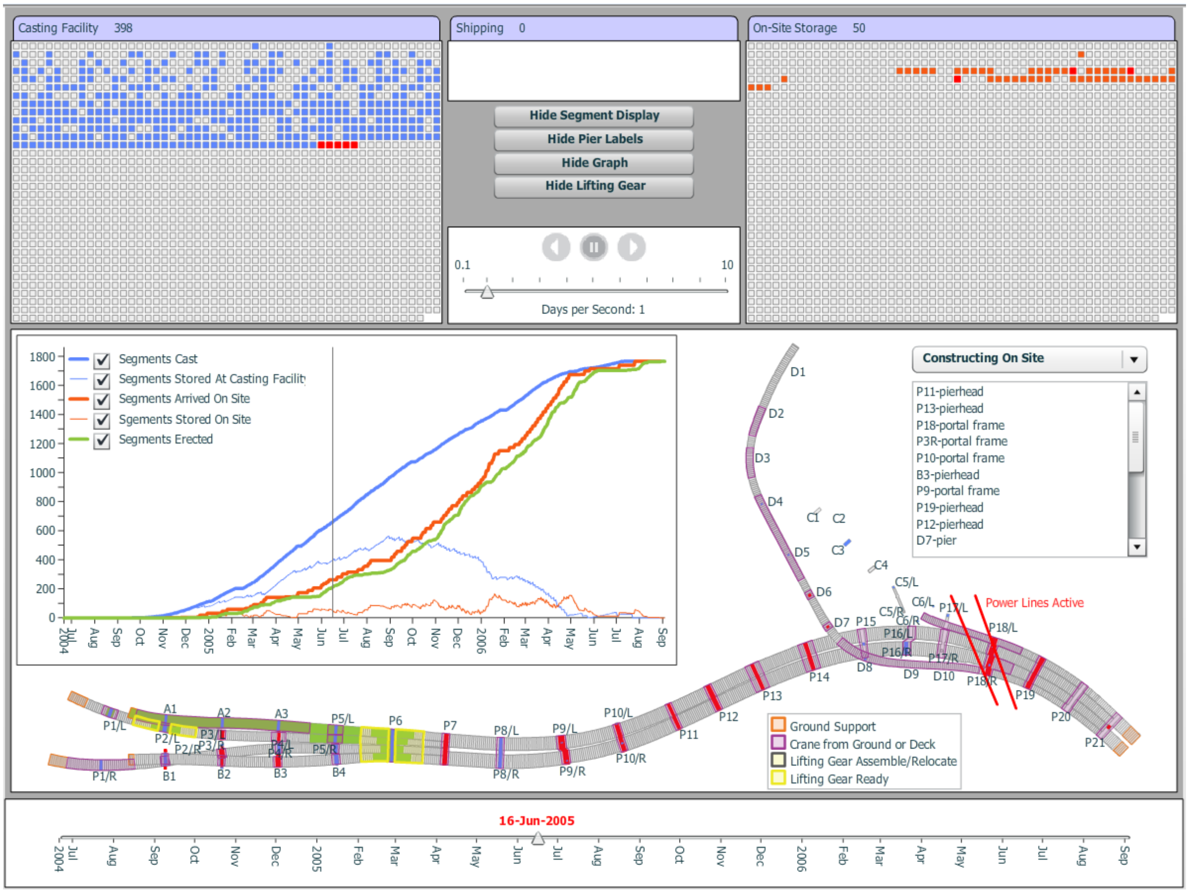

Fig 2. CGE used to support a delay and disruption claim on the construction of a viaduct

At designated stages in the workshop, the participants were asked to provide binary responses to structured questions asked by the presenter (Table 1). The responses, which were recorded, prompted discussion that was captured and reported.

Simulation

Following the experts' discussion, the second assessment developed the findings and assessed the proposed concept through a simulation. This was required to demonstrate how modes of presentation can be incorporated into delay analysis. Given the legal sector's need to rigorously test new technology before use, simulations were chosen because they avoid the risk of failure on a live project by creating and testing a concept in a synthetic environment (Wieringa 2014). Although there is always be uncertainty about the integrity of a synthetic environment, greater credibility is given to the results obtained from testing a simulation in an environment as close as possible to the context it was intended to recreate (Zelkowitz and Wallace 1998). Therefore, to establish a realistic environment for testing, data were obtained from a case study of a construction dispute.

Case studies allow complex problems to be explored in a realworld context (Yin 2013). A synthetic environment was created using the case study of a dispute between steelwork contractors and concrete frame contractors whose works were sequential to complete a fast-tracked multistory office building. Empirical data were obtained from claim consultants, but because of the sensitive nature of the dispute, some of the information was limited and modified to preserve anonymity. However, this did not compromise the output. The claim represented a concrete frame contractor who was required to follow a mandatory sequence of works (Fig. 3). One of the principal delay events that contributed to the 147 days' delay beyond the agreed on practical completion date was slow progress by the steelwork contractor.

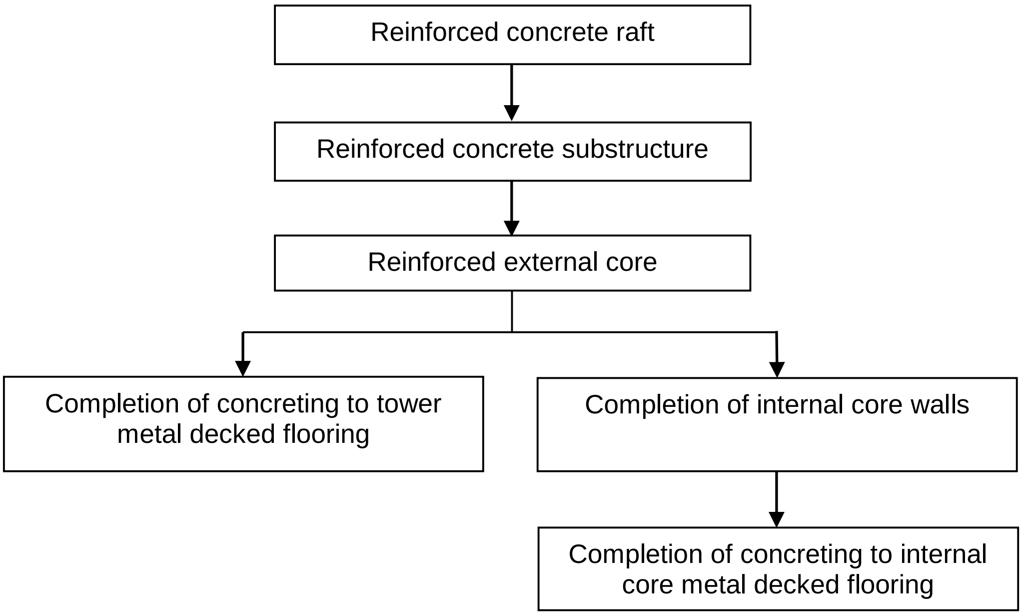

Fig 3. Concrete frame contractors mandatory sequence of works

A time impact analysis with one-month windows was used to analyze the delay on the project. It consisted of more than 3,500 interconnected activities. Although this approach provided a detailed mathematical analysis, it made understanding the cause and effect of delay challenging.

Incorporation of Modes of Presentation

A CGE, in the form of an interactive exhibit, was produced to represent one of the monthly windows. The interactive exhibit integrated all of the VARK modes of presentation with the delay analysis, along with current and past research findings, using a variety of software packages (Fig. 4). To create a fact-driven 4D model of the delay claim, a 3D model and the construction program were required. The original delay analysis was produced in programming software that did not interface with the construction sequencing software. Therefore, to use the delay analysis, the file was transferred through different programming packages until it could be converted into a file format that allowed it to be imported into the construction-sequencing software. Checks and modifications were undertaken to ensure that an exact replica of the analysis was presented.

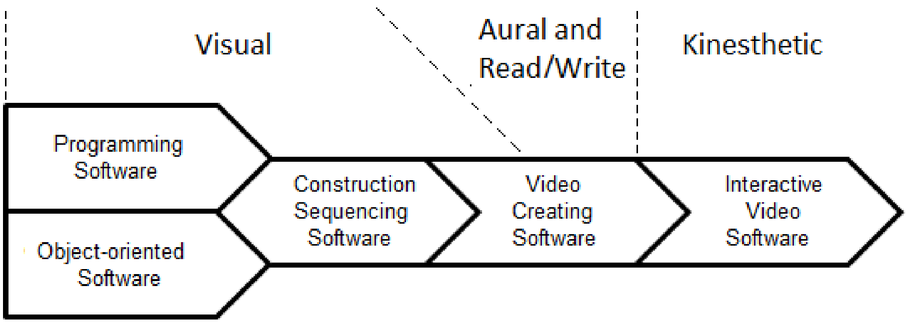

Fig 4. Software used to develop each mode of presentation

A 3D model of the project was not available and had to be created using object-oriented software. It was produced using technical drawings, design information, and photographs that were provided to the claim consultants. The model was then imported into the construction-sequencing software and the activities in the programming software were linked to the 3D objects. Appropriate camera angles and visualization techniques were employed to demonstrate as-planned (baseline) progress against the as-built (time-impacted) data. The visual output was recorded and edited using video-creating software and saved as a video file.

Aural narration, which summarized the report narrative, was recorded in the video-creating software to describe what was occurring on screen. The visual and aural recordings were carried out independently and were edited to enhance presentation. Text captions were then added in the video-creating software to provide additional explanation of the delay analysis. Caption length was limited so as not to compromise the visual appearance, but additional written information could be found through kinesthetic interaction. This was achieved by placing clickable tags on the written description of the delay event that contained additional information such as photographs, videos, graphs, and more detailed and cross-referenced descriptions.

SUITABILITY OF PROPOSED CONCEPT

Workshop Findings

At the time of the workshop, the 50 participants accounted for 50% of the individuals registered on the RICS panel of adjudicators. The data obtained from the workshop's structured questions are presented in Table 1. The workshop participants stressed that a CGE should display only fact and that the information driving the visual should be seen by viewers. To determine the value of CGE, some participants indicated a preference for interrogating the exhibit, but the necessity of this created a split in opinion. The majority of participants commented that interrogation was not fundamental and that, in its most basic form, the CGE could be used to give an overall impression of a claim. One participant stated that this would be advantageous in adjudications, where an adjudicator has a short time to understand a dispute and report his or her decision. However, some participants indicated that, although CGEs might be visually appealing and useful in swaying a jury, there would always be an element of doubt that they could accurately reflect the facts.

Table 1. Summary of workshop results

Question no.	Description	Yes response	
		Number	Percentage
1	Have you ever been provided with a CGE to support a construction claim?	16	32%
1a	Was the CGE useful in assisting your judgement?	7	44%
1b	Was the CGE not useful in assisting your judgement?	9	56%
2	Would you find CGE, like that demonstrated, useful in assisting your understanding of a construction claim?	22	44%
3	Do you feel there would be value in adding Aural and Read/Write functions to CGE's like that demonstrated?	47	94%

There was consensus among the participants that it is the responsibility of the CGE's creator to tell the viewer how it can be relied on. Furthermore, there was general agreement that the CGE should be kept as simple as possible and include sufficient explanation to communicate what is occurring on screen. The participants recommended showing actual progress against what was planned and using video and pictures as supporting evidence. It was also stated that the CGE could be useful to proactively manage a project.

Workshop Discussion

Less than a third of the workshop participants had been presented with a CGE during their career, which demonstrates that CGEs are not widely used to support construction claims. Of those who had encountered a CGE, the respondents did not indicate multiple experiences.

The ability to display the information driving the CGE will vary depending on the claim. For delay claims, the delay analysis should suffice and can be included and made visible as part of the CGE. The detail of the information included and displayed in the CGE depends on its purpose. It appeared that the workshop participants were unaware of the different degrees of CGE value, and this may have contributed to the divided response on the appropriateness of CGEs as supporting evidence. Therefore, the use of a narrative to explain how the viewer can rely on the CGE would be of benefit.

There may be a lack of confidence in CGEs because of personal views and the demographic of the job role. Some individuals, particularly those who have worked a large proportion of their lives without computers, tend to question whether the CGE is accurately representing the claim information. To remove this doubt, the native file can be provided to allow interrogation of the model. Nevertheless, the value of including all modes of presentation in the CGE was recognized by the majority of participants. Nearly all agreed that enhancing the read/write functions and adding aural narration to the existing visual and kinesthetic modes of presentation in the CGE would improve its value. Given the professional status and the sample size of the population, the findings indicate that modes of presentation can improve understanding of construction delays and that technology, if used correctly, can be a suitable enabler. To evaluate this concept, a simulation using case study data was developed and the research findings were applied.

SIMULATION OF PROPOSED CONCEPT

Proposed Interactive Exhibit

The innovation considers the technological capabilities of the legal system to provide a practical solution. The output, the interactive exhibit, incorporates the workshop findings and the recommendations found in related literature (Gibbs et al. 2014), as outlined in Table 2. These recommendations are applied and described in the Figs. 5–9 for specific times in the interactive exhibit to demonstrate how the slow progress of the steelwork contractor caused delay for the concrete frame contractor during one window of analysis.

Table 2. Incorporating the recommendations into the simulation

No.	Recommendation	Description
1	Cost benefit analysis	An evidential CGE (Burr, 2010) was deemed most appropriate for the multimillion pound claim.
2	Clearest form	Only steel and concrete works are displayed in the 3D model. These are colour coded and uninfluential resources were not included to avoid distraction. All four modes of presentation were used to assist with demonstrating the delay in its clearest form. • *Visual*: Fact driven as-planned and as-built 3D models [see No.3]. • *Aural*: Summarised report narrative played to describe what's occurring on screen. • *Read/Write*: Text boxes provide detail about delays as they occur and act as clickable tags, which can access further text and cross reference other evidence, when activated. • *Kinesthetic*: Clickable tags provide the viewer with the opportunity to interact with the exhibit.
3	Side by side comparison with timeline	The delay analysis is displayed and uses as-planned (baseline) progress against the as-built (time impacted) in a single Gantt chart. The delay analysis drives the as-planned and as-built 3D virtual models, which are placed side by side to allow for direct comparison.
4	Communication	There was communication between the 4D modeller and the delay analyst, with a final check to ensure the output was correct.

Fig 5. Interactive exhibit at 00:01

00 min 01 s: an aural description explains how the interactive exhibit can be used and provides background information for the delay claim; aural description of what is occurring on screen is provided throughout the exhibit.

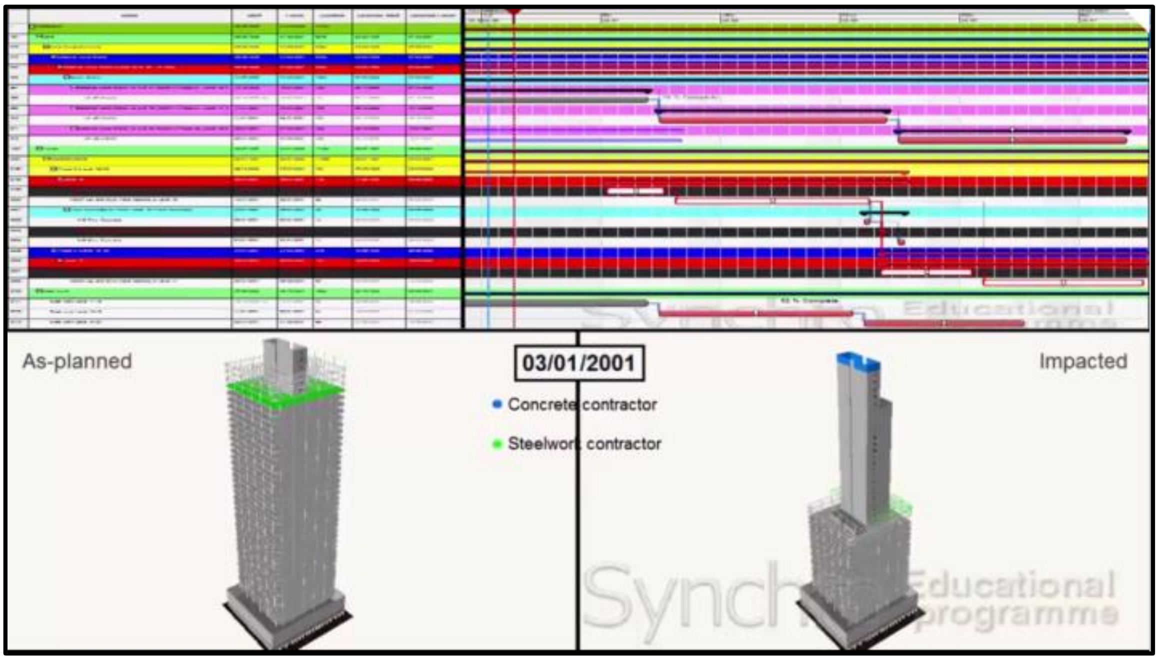

Fig 6. Interactive exhibit at 00:50

00 min 50 s: a side-by-side visual analysis of as-planned and asbuilt progress is presented; as the timeline progresses through the delay analysis, the camera angle pans both virtual models; activities performed by each trade are color coded to assist with differentiation: blue for the concrete contractor works and green for the steelwork contractor works.

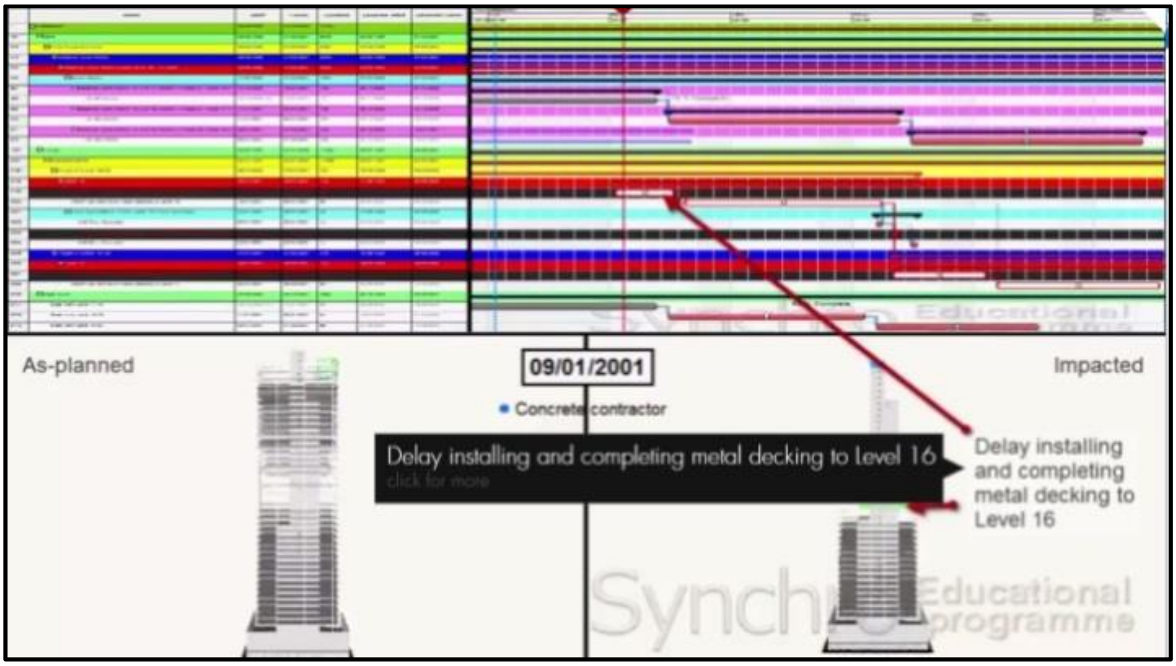

Fig 7. Interactive exhibit at 01:06

01 min 06 s: delay events are marked on the Gantt chart in black; for the duration of the delay event, black text boxes appear to provide a description of the delay; they act as the clickable tags that make the video interactive.

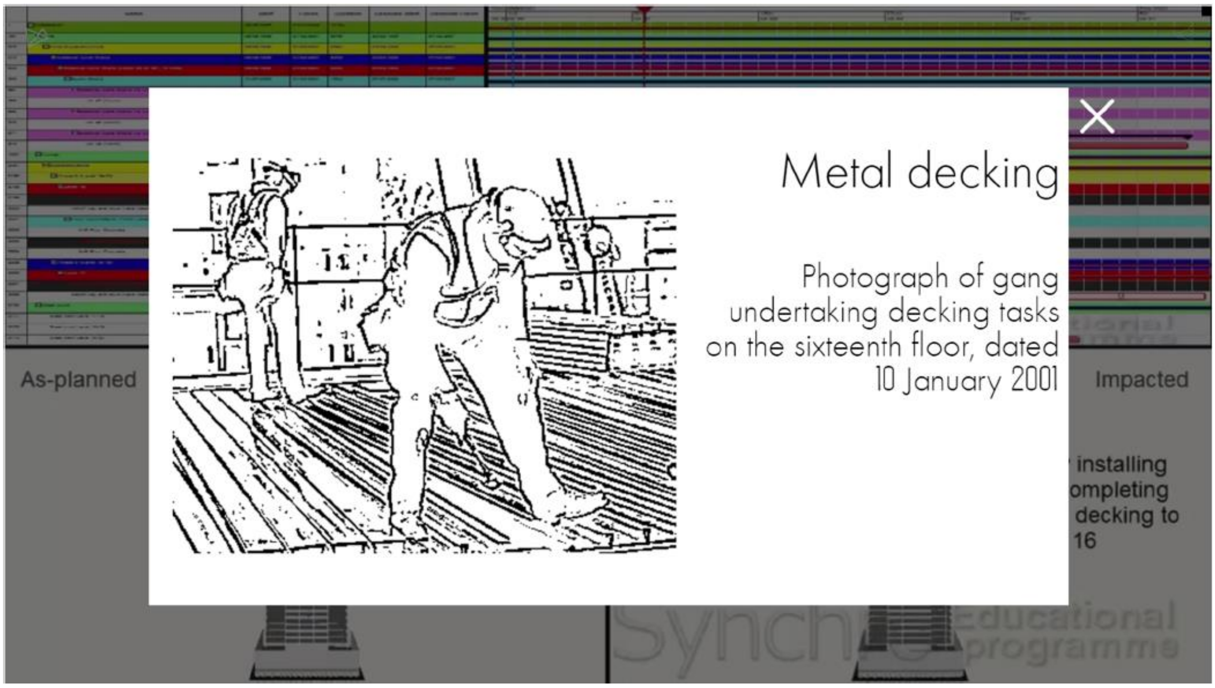

Fig 8. Interactive exhibit at 01:06 (interactive tag clicked)

01 min 06 s: when the tag is clicked, the exhibit is paused and a box containing additional information, such as pictures, videos, or text references to the report narrative, is displayed; if the tag is not clicked, the exhibit progresses as normal.

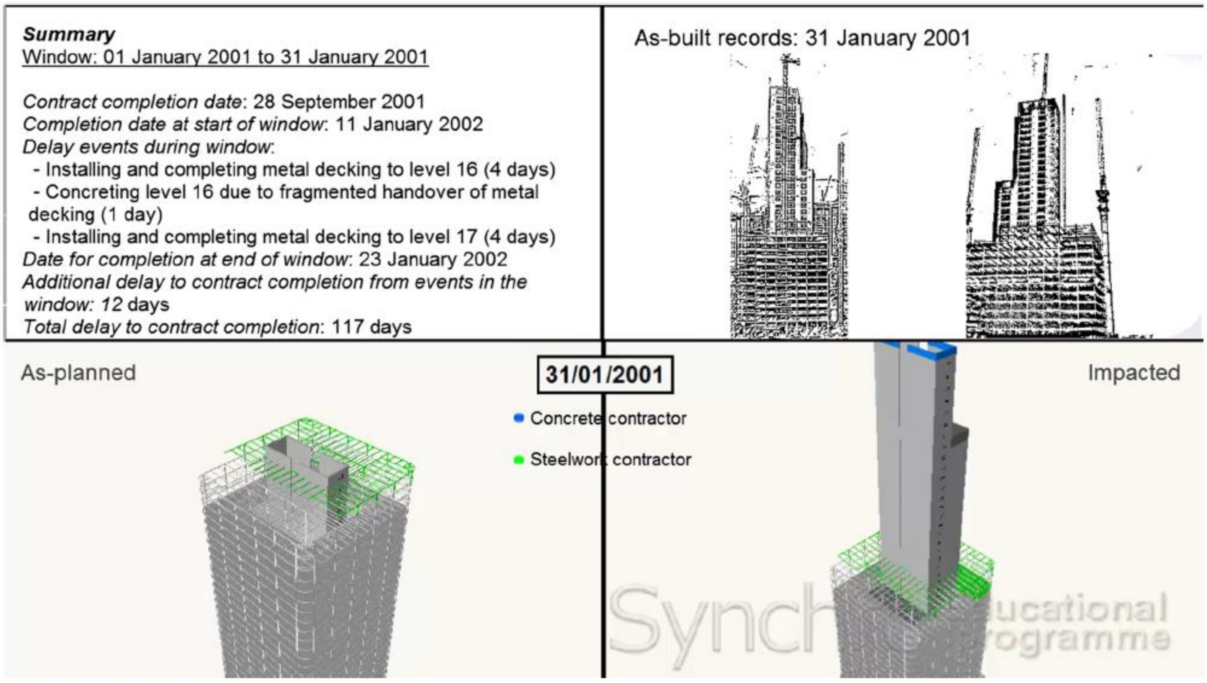

Fig 9. Interactive exhibit at 02:39

02 min 39 s: at the end of the exhibit, a summary is provided to show the effects of delay during the window; as-built records are included to allow comparison with the as-built 3D virtual model, which helps to ensure the integrity of the delay claim.

Interactive Exhibit Observations

The interactive exhibit provides an innovative way of understanding Gantt chart information. Instead of converting the data into a meaningful mental image to compare planned and actual progress, the need for this conceptualization is reduced and the proposed concept enhances understanding by incorporating modes of presentation into the analysis. The application of these modes of presentation into the interactive exhibit is summarized, and their benefits and limitations are presented in Table 3.

The development of the 4D model demonstrated the need for consistency between the granularity of the virtual model and the construction program. This is easier to achieve but less useful if undertaken retrospectively. Nevertheless, communication between the program creator and the 4D model developer is critical, and an appreciation of the different disciplines is beneficial; otherwise, problems can arise. For example, in the case study some of the steel columns stretched from the ground floor to the roof and the 3D model had to be reengineered for compatibility with the construction program's installation sequence. In contrast, some of the items in the delay analysis were too detailed and did not add value to the 4D model. This included noninfluential handover dates, which were hidden in the interactive exhibit to reduce onscreen distraction. Despite this, the text on the Gantt chart in the interactive exhibit remained small and difficult to read because it was required to be displayed in one view.

Further software challenges were encountered with the interoperability of software packages. Although the 3D virtual model was imported into the construction-sequencing software as required, the delay analysis and the construction-sequencing software did not directly interface. As a consequence, the native delay analysis file was transferred through different software packages to create a compatible file format. This resulted in data distortion, so alterations and checks were necessary to ensure consistency with the native file, which made for a timely process. To reduce doubt about the integrity of the analysis, the summary box at the end of the exhibit compared as-built photographs with the virtual model.

Table 3. Summary, benefits and limitations of each mode of presentation in the interactive exhibit

Mode of presentation	Summary	Benefits	Limitations
Visual	Simulation of delay analysis showing the side-by-side analysis of as-planned (baseline) progress and the as-built (time impacted).	Demonstrates the complex interdependency between trades. Side-by-side analysis shows change events and the effect on the project.	If 3D and 4D models do not exist, creating them can be resources intense. Issues with interoperability of software packages.
Aural	Aural explanation of what is occurring on screen. This is likely to be a summary of the written report narrative.	Can be turned on/off at viewer's discretion.	Detail might not be sufficient as a standalone item.
Read/Write	Text captions summarise key events and pieces of information.	Summarises and draws attention to key items.	Cannot be turned on/off when interactive exhibit is created. Detail might not be sufficient as a standalone item.
Kinesthetic	Novel way for the viewer to interact with the simulation and gain additional information using clickable "tags".	Simple and effective way to interact with the exhibit to gain additional information. Can be played on a handheld device to enhance Kinesthetic learning.	All senses cannot interact with digital technology for full Kinesthetic learning. Interaction is limited, viewer cannot navigate the model. Data held on a server external to those involved with the project.

Once the visual aspect of the model was developed, the video creating software made the incorporation of the read/write and aural modes of presentation straightforward. A soundtrack was not included in the exhibit because it might have distracted viewers, and slower speech and regular pauses were incorporated to allow time for information to be processed. This balance was achieved by editing the aural file in the video-creating software. To improve the impact of the exhibit, read/write and aural descriptions were limited, and any additional information required was made accessible via the interactive tags. If the information behind the tags were not to offer the required information to support a claim, a report narrative would have to be provided with the appropriate detail.

Nevertheless, the clickable tags promote kinesthetic learning through user interaction, and this learning style can be enhanced by viewing the interactive exhibit on a mobile device, allowing viewers to understand information away from their desk. This option is supported through private online access; however, it requires that the data be held on a third-party sever, which might create a barrier to adoption. Even so, it is anticipated that alternative ways of creating and viewing interactive exhibits will become available in the future.

Given the nature of video, the primary mode of presentation for the exhibit was shown to be visual with the other modes (aural, read/write, and kinesthetic) providing secondary support. Because it is impossible for all senses to interact with digital technology, incorporating kinesthetic modes of presentation into the delay analysis posed the greatest challenge. Furthermore, a video was required to support the aural and read/write modes. This eliminated the ability to interrogate the delay analysis in a 4D environment, which would have benefited kinesthetic learning. For this reason, a native file of the 4D model might be provided in addition to the interactive exhibit to allow for interrogation and enhanced kinesthetic learning.

Generally, the time impact analysis demonstrates how the VARK modes of presentation can assist with proactive control and retrospective analysis. The interactive exhibit appears the most suitable for construction claims; however, the resources required to produce it for proactive control may outweigh the overall value gained. Proactive control of delays requires fast decisions, but the interactive exhibit requires time and resources for its creation. Furthermore, those involved with decision making at this stage may not significantly benefit from improved understanding because they are likely to be familiar with the details of the project. Therefore, although recording the effects of change is important, some individuals might argue that time and resources would be better focused on overcoming delays than on reporting their effects in the form of an interactive exhibit. Still, the visual mode incorporating side-by-side comparison of as-planned and as-built 4D models might, in isolation, be used to proactively manage delays.

Overall, the interactive exhibit can address some of the challenges individuals face when trying to understand the effects of delay. The various VARK modes of presentation should enhance understanding for an individual with limited project or delay knowledge, which can improve the clarity of the claim and shift the balance of probabilities in a party's favor. Thus, it can be used to avoid the likelihood and severity of disputes.

CONCLUSIONS AND FUTURE RESEARCH

This research demonstrates how interactive exhibits can be used to improve understanding of delays for proactive control and retrospective analysis. Taking into account the level of information technology use in the legal sector, a practical solution was developed through two stages of assessment.

The first stage of assessment confirmed the suitability of using VARK modes of presentation to improve understanding of construction claims, and it produced requirements for future development. In line with the literature, industry experts identified that CGEs are not common forms of evidence for construction claims (Vidogah and Ndekugri 1998) and when they have been used to support claims, they have not always been helpful. The experts' suggestions for improvement were consistent with previous research (Gibbs et al. 2014), and their concerns mirrored some of the issues presented in the literature (Schofield 2011). This included informing viewers of how they can rely on the CGE for the reason that not all individuals are familiar with the different CGE categories (Burr and Pickavance 2010). If this is not communicated, it can cause the CGE's integrity to be questioned, a situation that can be exacerbated if the CGE cannot be interrogated. To avoid doubt, it is recommended that the native 4D file be made available so the data can be independently analyzed if required. The integrity of the CGE as evidence could be assisted by the inclusion of the VARK modes of presentation, which can be used to explain and cross-reference what is occurring on screen.

The second stage of assessment developed the workshop findings and demonstrated that all four VARK modes of presentation can be successfully integrated into an interactive exhibit. However, doing so was not without its challenges. Integrating the different modes of presentation evenly into the CGE is restricted by technology. In the proposed concept, the visual mode appears to be primary, with the other modes attached. Therefore, some of the perceived benefits of the interactive exhibit may be attributable to the side-by-side comparison of as-planned and as-built progress. Another challenge is interoperability. Literature on interoperability for 4D modeling is lacking, and although the current study goes some way to demonstrate the challenges, additional research into software interoperability and the granularity of detail for the simultaneous production of a program and 3D virtual model is required.

The time impact analysis demonstrates how the proposed concept can be used for both proactive control and retrospective analysis, but the research exemplifies the challenge of creating a holistic tool (Scott 1990). It is perceived that the interactive exhibit will add the greatest value to construction claims because it can assist with communicating causality, responsibility, and quantum in its clearest form. This is consistent with literature on 4D modeling applicability that finds that the modeling's greatest value is to those with a lack of site-related knowledge (Mahalingam et al. 2010). Therefore, the interactive exhibit can improve the standard of evidence and tip the balance of probabilities; however, further research is required to test the concept in practice and additional value can be gained through analysis of nonlinear projects with different methods/ classifications of delay analysis that require different levels of communication (Ng et al. 2004). Further research is also required to determine the added value of the interactive exhibit for proactive control.

Overall, the research aim, reducing the likelihood and severity of construction disputes, is addressed through the development of the interactive exhibit, which can be used to accelerate and improve understanding of project delay through the VARK modes of presentation. It is suggested that the interactive exhibit be used as a supportive tool and not as a replacement for conventional methods. Before the proposed concept is incorporated into practice, additional stages of assessment should be undertaken.

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REFERENCES

List of Cases

Balfour Beatty Construction v. Lambeth London Borough Council (2002) EWHC 597.

Clydebank Engineering Co. v. Don Jose Yzquierdo y Castaneda (1905) AC 6.

Hadley v. Baxendale (1854) EWHC Exch J70.

Hunte v. E Bottomley & Sons (2007) EWCA Civ 1168.

National Museums and Galleries on Merseyside Board of Trustees v. AEW Architects and Designers Ltd. (2013) EWHC 3025 (TCC).

Robinson v. Harman (1848) 1 Exch 850; 154 E.R.

Works Cited

AACE (Association for the Advancement of Cost Engineering). (2011). “Forensic schedule analysis. TCM framework: 6.4—Forensic performance assessment.” AACE Int. Recommended Practice No. 29R–03, Morgantown, WV.

Alkass, S., Mazerolle, M., Tribaldos, E., and Harris, F. (1995). “Computer aided construction delay analysis and claims preparation.” Constr. Manage. Econ., 13(4), 335–352.

Arcadis. (2015). “Global construction dispute report 2015: The higher the stakes, the bigger the risk.” Amsterdam, the Netherlands.

Arditi, D., and Pattanakitchamroon, T. (2006). “Selecting a delay analysis method in resolving construction claims.” Int. J. Project Manage., 24(2), 145–155.

Baldonado, M., and Kuchinksy, A. (2000). “Guidelines for using multiple views in information visualization.” Proc., Advanced Visual Interfaces Conf., ACM, New York, 110–119.

Bayraktar, M., Arif, F., Hastak, M., and Gad, N. (2012). “Judiciary’s use of the critical path method to resolve construction claims.” J. Legal Affairs Dispute Resolut. Eng. Constr., 10.1061/(ASCE)LA.1943-4170 .0000079, 10–16.

Boyle, R. (2012). “Applying learning-styles theory in the workplace: How to maximize learning-styles strengths to improve work performance in law practice.” St John’s Law Review, 79(1), 97–126.

Braimah, N. (2013). “Construction delay analysis techniques—A review of application issues and improvement needs.” Buildings, 3(3), 506–531.

Braimah, N., and Ndekugri, I. (2008). “Factors influencing the selection of delay analysis methodologies.” Int. J. Project Manage., 26(8), 789–799.

Burr, A., and Pickavance, K. (2010). “The use of visualisations in case presentation and evidence.” Constr. Law J., 26(1), 3–17.

CIOB (Chartered Institute of Building). (2008). “Managing the risk of delayed completion in the 21st century.” Berkshire, U.K.

CIOB (Chartered Institute of Building). (2011). Guide to good practice in the management of time in complex projects, Wiley-Blackwell, West Sussex, U.K.

Clark, R., and Mayer, R. (2008). E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning, 2nd Ed., Pfeiffer, San Francisco.

Conlin, J., and Retik, A. (1997). “The applicability of project management software and advanced IT techniques in construction delays mitigation.” Int. J. Project Manage., 15(2), 107–120.

Cooper, M. (1999). “The use of demonstrative exhibits at trial: Practitioner’s guide.” Tulsa Law J., 34(3), 567–578.

CRC (Cooperative Research Centre). (2007). “Dispute avoidance and resolution: A literature review.” Rep. No. 1, Brisbane, QLD, Australia.

Farrow, T. (2001). “Delay analysis—Methodology and mythology.” Society of Construction Law, Leicestershire, U.K.

Feigenson, N., and Dunn, M. (2003). “New visual technologies in court: Directions for research.” Law Human Behav., 27(1), 109–126.

Feigenson, N., and Spiesel, C. (2011). Law on display, NYU Press, New York.

Fenwick Elliott. (2012). Dictionary of construction terms, Informa Law, London.

Fisher, R. (2004). “The problem-solving workshop as a method of research.” Int. Negotiation, 9(3), 385–396.

Fleming, N. (1995). “I’m different; not dumb. Modes of presentation (VARK) in the tertiary classroom.” Proc., 1995 Annual Conf. of the Higher Education and Research Development Society of Australasia (HERDSA), Vol. 18, HERDSA, Hammondville, NSW, Australia, 308–313.

Fleming, N. D., and Mills, C. (1992). “Not another inventory, rather a catalyst for reflection.” Improve the academy, Univ. of Nebraska, Lincoln, NE, 137–146.

Flyvberg, B. (2014). “What you should know about megaprojects and why: An overview.” Project Manage. J., 45(2), 6–19.

Gibbs, D., Emmitt, S., Ruikar, K., and Lord, W. (2013). “An investigation into whether building information modelling (BIM) can assist with construction delay claims.” Int. J. 3-D Inform. Model., 2(1), 45–52.

Gibbs, D., Emmitt, S., Ruikar, K., and Lord, W. (2014). “Recommendations on the creation of computer generated exhibits for construction delay claims.” Constr. Law J., 30(4), 236–248.

Gibbs, D., Lord, W., Emmitt, S., and Ruikar, K. (2015). “Building information modelling.” Constr. Law J., 31(3), 167–179.

Girbacia, F. (2012). “Evaluation of cognitive effort in the perception of engineering drawings as 3D models.” Proc., 2012 Int. Conf. on Advances in Computer-Human Interactions, IEEE, New York, 247–250.

Haidar, A., and Barnes, P. (2011). Delay and disruption claims in construction: A practical approach, ICE, London.

Kangari, R. (1995). “Construction documentation in arbitration.” J. Constr. Eng. Manage., 10.1061/(ASCE)0733-9364(1995)121:2(201), 201–208.

Kelley, J. (1961). “Critical-path planning and scheduling: Mathematical basis.” Oper. Res., 9(3), 296–320.

Koo, B., and Fischer, M. (2000). “Feasibility study of 4D CAD in commercial construction.” J. Constr. Eng. Manage., 10.1061/(ASCE)0733 -9364(2000)126:4(251), 251–260.

Kumaraswamy, M. (1997). “Conflicts, claims and disputes in construction.” Eng. Constr. Archit. Manage., 4(2), 95–111.

Lazarus, D., and Clifton, R. (2001). “Managing project change: A best practice guide.” Construction Industry Research and Information Association (CIRIA), Westminster, U.K.

Leite, W., Svinicki, M., and Shi, Y. (2010). “Attempted validation of the scores of the VARK: Learning styles inventory with multitrait-multimethod confirmatory factor analysis models.” Educ. Psychol. Meas., 70(2), 323–339.

Love, P., Davis, P., Ellis, J., and Cheung, S. (2010). “Dispute causation: Identification of pathogenic influences in construction.” Eng. Constr. Archit. Manage., 17(4), 404–423.

LSN (Legal Support Network). (2015). “Legal IT landscapes 2015: Tomorrow’s technologies for competitiveness and efficiency.” Surrey, U.K.

Mahalingam, A., Kashyap, R., and Mahajan, C. (2010). “An evaluation of the applicability of 4D CAD on construction projects.” Autom. Constr., 19(2), 148–159.

Mayer, R. (2009). Multimedia learning, 2nd Ed., Cambridge University Press, New York.

Mayer, R., and Anderson, R. (1991). “Animations need narrations: An experimental test of a dual-coding hypothesis.” J. Educ. Psychol., 83(4), 484–490.

Mayer, R., Heiser, J., and Lonn, S. (2001). “Cognitive constraints on multimedia learning: When presenting more material results in less understanding.” J. Educ. Psychol., 93(1), 187–198.

MoJ (Ministry of Justice). (2013). “Transforming the CJS: A strategy and action plan to reform the criminal justice system.” The Stationery Office, Norwich, U.K.

MoJ (Ministry of Justice). (2014). “Transforming the criminal justice system: Strategy and action plan—Implementation update.” The Stationery Office, Norwich, U.K.

Moosavi, S., and Moselhi, O. (2014). “Review of detailed schedules in building construction” J. Legal Affairs Dispute Resolut. Eng. Constr., 10.1061/(ASCE)LA.1943-4170.0000142, 05014001.

Narayanan, A., and Hibbin, S. (2001). “Can animations be safely used in court?” Artif. Intell. Law, 9(4), 271–294.

NBS (National Building Specification). (2014). “NBS international BIM report 2013.” RIBA Enterprises, London.

NBS (National Building Specification). (2015). “National construction contracts and law survey 2015.” RIBA Enterprises, London.

Ng, S., Skitmore, M., Deng, M., and Nadeem, A. (2004). “Improving existing delay analysis techniques for the establishment of delay liabilities.” Constr. Innovation, 4(1), 3–17.

Olatunji, O. (2016). “Constructing dispute scenarios in building information modeling.” J. Legal Affairs Dispute Resolut. Eng. Constr., 10.1061/ (ASCE)LA.1943-4170.0000165, C4515001.

Pensa, S., Masala, E., Lami, I., and Rosa, A. (2014). “Seeing is knowing: Data exploration as a support to planning.” Proc. Inst. Civ. Eng., 167(5), 3–8.

Pickavance, K. (2007). “Using advanced forensic animations to resolve complex disruption claims.” Society of Construction Law, Leicestershire, U.K.

Pickavance, K. (2010). Delay and disruption in construction contracts, 4th Ed., Sweet & Maxwell, London.

Ramanathan, C., Narayanan, S., and Idrus, A. (2012). “Construction delays causing risks on time and cost—A critical review.” Aust. J. Constr. Econ. Build., 12(1), 37–57.

RIBA (Royal Institute of British Architects). (2012). “BIM overlay to the RIBA outline plan of work.” London.

Schofield, D. (2011). “Playing with evidence: Using video games in the courtroom.” Entertain. Comput., 2(1), 47–58.

SCL (Society of Construction Law). (2002). “Delay and disruption protocol.” Leicestershire, U.K.

SCL (Society of Construction Law). (2015). “Rider 1: The society of construction law delay and disruption protocol.” Leicestershire, U.K.

Scott, S. (1990). “Keeping better site records.” Project Manage., 8(4), 243–249.

Spanjers, I., Gog, T., Wouters, P., and Merriënboer, J. (2012). “Explaining the segmentation effect in learning from animations: The role of pausing and temporal cueing.” Comput. Educ., 59(2), 274–280.

Stenzler, M., and Eckert, R. (1996). “Interactive video.” SIGCHI Bull., 28(2), 76–81.

Sung, E., and Mayer, R. (2012). “When graphics improve liking but not learning from online lessons.” Comput. Human Behav., 28(5), 1618–1625.

Tieder, J. (2009). “Methods of delay analysis and how they are viewed by the United States legal system.” Society of Construction Law, Leicestershire, U.K.

Trauner, T., Manginelli, W., Lowe, J., Nagata, M., and Furniss, B. (2009). Construction delays: Understanding them clearly, analysing them correctly, 2nd Ed., Elsevier, London.

Vidogah, W., and Ndekugri, I. (1998). “A review of the role of information technology in construction claims management.” Comput. Ind., 35(1), 77–85.

Whatley, P. (2014). The project planning handbook, Troubador, Leicester, U.K.

Wieringa, R. (2014). “Empirical research methods for technology validation: Scaling up to practice.” J. Syst. Software, 95, 19–31.

Williams, T., Ackermann, F., and Eden, C. (2003). “Structuring a delay and disruption claim: An application of cause-mapping and system dynamics.” Eur. J. Oper. Res., 148(1), 192–204.

Williams, T., Eden, C., Ackermann, F., and Tait, A. (1995). “The effects of design changes and delays on project costs.” J. Oper. Res. Soc., 46(7), 809–818.

Wing, T. (2016). “A timeless motto for dispute resolution: Prevention is better than cure.” J. Legal Affairs Dispute Resolut. Eng. Constr., 10.1061/(ASCE)LA.1943-4170.0000169, C1815001.

Yin, R. (2013). “Validity and generalization in future case study evaluations.” Evaluation, 19(3), 321–332.

Zelkowitz, M., and Wallace, D. (1998). “Experimental models for validating technology.” Computer, 31(5), 23–31.