A Case Study Investigation into the use of Computer Generated Visualisations to Assist with Construction Delay Claims

David-John Gibbs[1], Stephen Emmitt[2], Kirti Ruikar[3], Wayne Lord[4]

Abstract

It is probable that a construction project will encounter some form of delay which can have differing adverse effects on the various parties involved in the works. Those affected by the delay are entitled to claim a form of compensation but the burden of proof lies with the party making the assertion. Analysing the cause and effect of a delay event is difficult given the ever increasing complexity of construction works; thus, experts are often employed to undertake the task but face the challenge of clearly representing and communicating their findings. This paper identifies the accepted traditional methods of representing construction delays and explores how they could be assisted through technological developments in computer generated visualisations, which have gained growing acceptance within legal proceedings. An in-house case study presents two different visualisations, one in 2D and one in 4D, which were developed in an attempt to assist with the same delay claim. The benefits, limitations and areas of improvement are discussed for each and an overall recommendation on the potential use of visualisations to assist with construction delay claims is presented. The paper recognises further investigation into the use of Building Information Modelling to support delay claims which forms part of on-going research towards an engineering doctorate.

Key words: BIM, claims, delays, disputes, visualisation.

1. Introduction

Construction projects are becoming increasingly complex, yet tender values in the UK are decreasing (BCIS, 2012). The more complex a construction project, the more likely it is to encounter time delays, which may result in financial implications (CIOB, 2008). Given that 70% of UK construction projects are delivered late (HM Treasury, 1999) and that organisations cannot financially absorb the difference from what was planned, if the delay is beyond the organisations control, it is likely that a claim will be made for some form of

[1] Research Engineer; DAQS Ltd; Stokes Suite, Unit 7a, East Bridgford Business Park, Kneeton Road, East Bridgford, Nottingham, England, NG13 8PJ; D.Gibbs@lboro.ac.uk.
[2] Professor of Architectural Technology; Loughborough University; School of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, England; S.Emmitt@lboro.ac.uk.
[3] Senior Lecturer; Loughborough University; School of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, England; K.D.Ruikar@lboro.ac.uk.
[4] Lecturer; Loughborough University; School of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, England; W.E.Lord@lboro.ac.uk.

compensation. If the claim is not accepted, the project may go into dispute. The number of construction disputes in the UK has risen by a third during the recent recession (Sweet & Maxwell, 2010) with both the value and length of the average UK construction dispute increasing by US$2.7million and 1.95months (EC Harris, 2012). Owing to the extensive resources required to undertake a construction claim, the divergence away from the proactive management of the organisation, as well as the migration of cash flow out of the construction industry when disputes occur, it is imperative that steps are made to improve the claim process.

This paper investigates the use of computer generated visualisations to assist with construction delay claims, an area in which to date there has been very little published research. The research reported in this paper is based on an in-house case study which presents two different visualisation approaches, one in 2D and one in 4D, which were developed to assist with the same delay claim.

2. Background

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). In this paper, the term delay refers to the non-completion of works by a date set in the construction contract (Fenwick Elliott, 2012). Therefore, the process of analysing delays can be viewed as the forensic investigation into an issue which has caused the project to overrun on time (Farrow, 2001). This is distinctly different from disruption, a term generally conjoined with delay, which investigates loss of efficiency due to a lower productivity or an interference with progress (Cooke, 2009). The topic of disruption is not covered in this paper; however, 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 (Trauner, 2009). 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 claimant to receive compensation, a construction delay claim must be made. This is broken down into three stages: causation, liability and quantum, all of which can prove a challenge for delay analyst (Williams, 2003).The burden of proof is placed with the claimant to prove each of these by showing on the balance of probabilities through cause and effect (Carnell, 2000). The balance of probabilities can then be shifted based on the standard of evidence, with stronger evidence required for more severe cases.

Construction programmes are the most common way to represent the cause and effect of delays and a variety of methodologies are available which use them, but some are preferred to (SCL, 2002). The chosen approach will be influenced by a variety of factors (Braimah, 2008); therefore, the choice of methodology should be the one which best represents the claim (Bubshait, 1998). It is argued that the most reliable of these methodologies is Time Impact Analysis which breaks the construction programme into a series of windows, each with their own baseline, and re-sequences in line with as-built activities to analyse the relationships and durations of individual delay events by inserting them into each window to identify the event and the delay caused in that period (Arditi, 2006).

The findings from the analysis must be supported by a narrative, which will attempt to explain the claimants interpretation of what occurred on the project. Visual information is preferred to oral information as it improves understanding and retention (Keane, 2008); thus it allows for a more informed decision to be made. At present, the submission of a delay claim may involve numerous lever arch files with complex construction programmes and supporting evidence. Although accepted as a means to show cause and effect, the various delay analysis methodologies can be difficult to understand (Kumaraswamy, 2003). This is emphasised by Humphrey Lloyd QC in Balfour Beatty Construction v. London Borough of Lambert:

“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.”

Furthermore, deciphering supporting information to allow for an informed judgement to be made can prove a challenging task, especially interpreting technical construction drawings (Dziurawiec, 1986). This is apparent in Hunte v. Bottomley where Arden L.J. 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.”

In an attempt to combat these problems, the courts are moving closer to e-disclosure and the use of screens as a method of communication. Therefore, the potential to use modern technology, particularly computer generated visualisations, to represent construction delays is possible. With continual developments in computer hardware along with the reductions in its cost, there has, and continues to be, a rise in the quality of computer generated visualisations. The definition of visualisation is open to interpretation and its meaning will vary between individuals. To some, a construction programme is a visualisation; whereas others, a simple line may suffice. In general, the term relates to a visual representation of information to enhance understanding (Card, 1999). For the purpose of this paper, ‘visualisations’ are Computer Generated Imagery (CGI) of tangible construction works which represent the progress of the project at a point in time.

Since the 1980s the entertainment industry has developed CGI for the internet, television, computer/video games and film (Parent, 2012). These platforms have progressed rapidly because the information is stored digitally, which allows it to be enhanced through bespoke software packages. Despite its rapid uptake in this sector, 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 (Tizzard, 1994); however, the current level and use of CAD within the industry is extremely varied, with 35% of organisations not using CAD (NBS, 2012). This could be attributed to the fact that although the information is electronic, it is uncoordinated and must be interpreted by individuals; thus, it is little different to the traditional drawing board (Sacks, 2004).

Within the construction industry, visualisations are predominantly used in architectural design, but their benefits can be realised throughout the construction lifecycle (Bouchlaghem, 2005). Their main benefit is assisting with understanding and communication. The value of visualisations can be extended to legal proceedings and their use is expected to rise as courts are becoming increasingly technologically sophisticated (Narayanan, 2001). Visualisations have assisted the courtroom in the 1998 UK inquiry into the events of Bloody Sunday in Londonderry 1972 and the 2001 Carla Terry murder case in Connecticut. The criteria for visualisations to be accepted as supporting evidence are identified in the latter case as:

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

Unfortunately, delay claims have not advanced in the same manner and the technology associated with them lags behind that of other stages in the lifecycle of a construction project (Vidogah, 1998). Pickavance (2007) identifies how technology can be used to create animations of tangible construction works to support construction disruption claims. Using both static and dynamic images to visually represent the cause and effect of disruption, the research highlights the importance of a side by side comparison of as-planned v. as-built progress. If used correctly, this method may be suitable in some adjudications and arbitrations (Pickavance, 2010); however, its value as evidence will vary depending on how it is employed and the supporting documentation (Schofield, 2005).

Numerous software providers offer products which allow you to virtually construct a construction project. The rise 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 (Cabinet Office, 2011) through the process of recording all of a project's information throughout its lifecycle in one, central, electronic, location. This information is 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 instead places objects with rules and parameters which determine both geometric and non-geometric properties and features (Eastman, 2011). The relationships and constraints between objects ensure realistic connections between elements and when designed in a single source model, a change to an object in one view will automatically update all other views and linked information. Through the coordinated information, multiple dimensions become available. These include 4D (time), 5D (cost) and 6D (FM) (RIBA, 2012) where a change in any view or dimension will instantly change all dimensions, views and report the most up-to-date information on the project. The benefits of this to assist with delay analysis are discussed by Gibbs (2012) while the process of BIM is also recognised as being able to assist with dispute systems (Greenwald, 2012).

3. Method

In order to determine how visualisations can assist with construction delay claims, primary data was collected through an in house case study. The use of a case study as a viable research methodology for construction claims is enhanced through Pickavance's (2007) research. Although the conclusions drawn from the research will be specific to a single project, the lessons learnt should be transferable. The author was unable to assist with the delay claim as it occurred before they joined the organisation and the dispute remains strictly confidential; therefore, the level of detail in the paper has been limited.

3.1. 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 for 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 this, computer generated visualisations were explored as a method of communication.

3.2. 2D visualisation

A prototype 2D visualisation of area 'A' was created by a delay analysts using Microsoft Excel to determine whether a visualisation would offer clarity on the delay claim (Figure 1). The Excel visualisation compares as-planned v. as-built progress side by side for the North, South, East and West faces of the building. Each floor compromises of the key sequencing activities required for its completion which include: deck installed, scaffolding, edge protection, freedom to complete floor and floor compete. Individual colours were applied for each activity and represented on each level at all four faces of the building when complete. The progress of the works were automated by linking the model to a bespoke Microsoft Excel construction programme in a separate tab, which automated side by side progress over time. The visualisation could also be used to demonstrate the exact progress for a point in time.

The benefits associated with the visualisation were clear to the Client who decided to progress the concept further into 4D, which subsequently halted the developments of the 2D visualisation. As the claim consultants did not have expert skills in virtual modelling, an external organisation was employed to create a visualisation of the works. Under the Clients request, communication was not allowed between the parties.

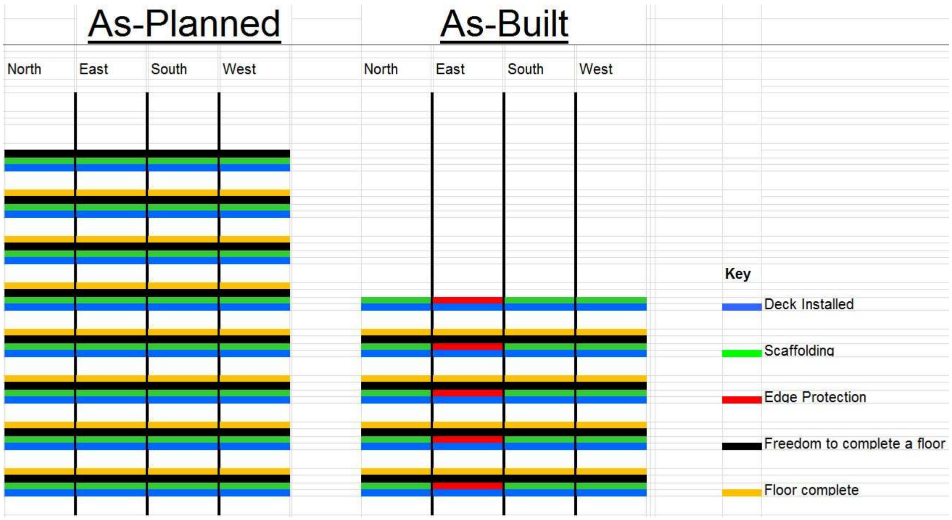

Figure1: Snap shot of a buildings progress from the 2D visualisation

3.3. 4D visualisation

A 4D visualisation of the Clients work was created by a virtual modelling organisation using Synchro. An open viewer of the software was obtained which allowed the visualisation to be viewed and analysed by the claims consultants, although no alterations could be made.

The visualisation incorporated all of the Client’s work which included all of the concrete superstructure levels which were individually coloured for each level (Figure 2). The visualisation was linked to an as-built programme within the software to create a fourth dimension, time. Under the 4D visualisation, the delayed elements were highlighted in red, returning back to the original floor level colour once the delay had passed.

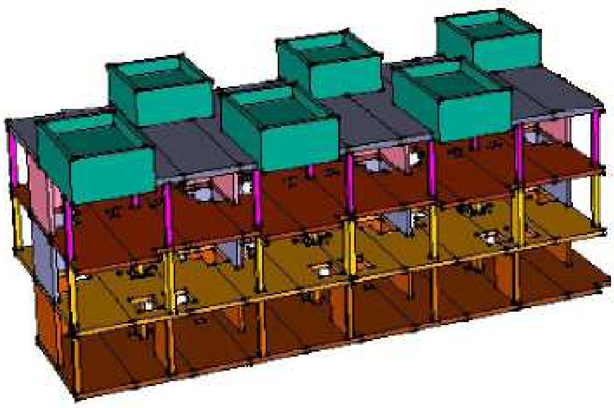

Figure 2: Snap shot of a building from the 4D visualisation

4. Analysis

4.1. 2D visualisation

4.1.1. Benefits

The 2D visualisation provides an easy to understand representation of the causes of delay on the project. The visualisation identifies five colour coded elements of sequencing works which make up the construction of each floor of the project. Through automated sequencing which shows as-planned v. as-built progress side by side, the visualisation demonstrates which elements are delayed for a point in time in relation to all faces of the project. Seeing all faces of the project simplified the understanding of how 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 automation can be paused, or a specific date selected, to represent progress at a point in time.

4.1.2. Limitations

Despite the apparent benefits of the 2D visualisation, it was not fully developed given the Clients request for the 4D visualisation and their monetary restraints; thus, limitations exist. Some of these limitations would have been tackled if the visualisation had been continually developed; others are inherent in the software.

Had additional time and resources been available to develop the 2D visualisation, it would have included additional activities involved in constructing the project. In its current state, the 2D visualisation 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 Excel, the records available from the Client did not allow for its straightforward incorporation.

Whilst an extremely powerful piece of software, Microsoft Excel is not developed to assist with construction delay claims; therefore, limitations exist, with particular regard to representation. The visualisation is not eye-catching and may not retain an individual's attention, an importance expressed by Keane (2008). The visualisation is also not to scale and does not represent the site layout or space available between elements of the areas, which may give a misconception of the amount of work undertaken and incomplete. This limitation is enhanced as the visualisation only shows one building in an area. Although this may be suitable for a single tower block, if all buildings on the particular project were included on one spreadsheet, it would become difficult to understand. Consequenlty, if the site has not been visited by those passing judgement, it would not assist with understanding the project, a problem identified in Hunte v. Bottomley.

Furthermore, the visualisation is not linked to a construction programme which recognises logic and a duplication of effort is required to ensure the creation of an accurate construction programme which is transferred correctly into Microsoft Excel format.

4.1.3. Possible improvements

As the 2D visualisation was developed in a Microsoft Office software package, it is extremely interoperable. The Excel visualisation does not utilise this and the possibility exists to add annotations and link information and documents, such as the narrative, delay programme or photographs, to the visualisation to provide clarity and supportive evidence.

While the Excel model simply represents construction delays, it is limited through the software on how it is represented. Therefore, the same process could be followed using another piece of software which, if available, would make the visualisation more appealing to the eye whilst also being linked to the original delayed construction programme.

4.2. 4D visualisation

4.2.1. Benefits

The 4D visualisation provides an accurate, detailed, virtual representation of the construction works which were undertaken by the Client. This allows the governing body to clearly understand the construction site without ever having to visit. With the ability to pan around the visualisation 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 virtually see the construction of the building without having to understand the construction programme in detail, a challenge encountered in Balfour Beatty Construction v. London Borough of Lambert.

4.2.2. Limitations

Despite some of the benefits realised in the 4D visualisation, it is not useful in conveying the cause and effect relationship of the delay events and subsequently was not used to support the delay claim.

The main limitation associated with the 4D visualisation is that it does not represent as-planned v. as-built progress side by side, as promoted by Pickavance (2007). Instead, both construction programmes are linked to one visual representation of the works, with colour coding depicting elements in delay. This method of representing delay does not provide a clear insight into the as-built progress of the works as the visualisation appears to progress at the as-planned rate but under different colours. Therefore, the stop-start relationship of the works is not clear and the delayed elements are not easy to understand. Given the restrictions of the software no annotations, links or photographs could be included to assist with understanding. Furthermore, despite the ability to pan around the visualisation, it was not possible to see all faces of the building at once. With the single view window of the project, it was not possible to see the effect of scaffolding restriction on sequencing works for all faces of the building at one moment in time. This was not supported through the emission of scaffolding objects within the visualisation. The visualisation 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, which the software supported that would have assisted with understanding the cause and effect of delays.

4.2.3. Possible improvements

The limitations of the 4D model could have been mitigated if direct contact was allowed between the claim consultants and the virtual modelling organisation. The reason why communication was not allowed is unknown, but it is expected to be due to confidentiality reasons given the legal situation of the case. It is thought that the individuals developing the visualisation had no experience of delay analysis; therefore, if direct communication was allowed, the delay analysts would have been able to instruct the virtual modelling organisation on the effective use of the visualisation to represent their findings. This would have solved the main problem of not having as-planned v. as-built progress views side by side. This function is not included in all software packages; however, the software used in this particular case is capable. Additionally, the software could have been used to generate multiple angles, or snapshots, of the project in one view for an exact moment in time. This would allow the effect of delay to be analysed on the project at one point in time.

The 4D visualisation could be further enhanced through attaching or linking information which relate to the delay report. If this is not available in the software, a voice recorded description of the analysis which plays over the visualisation would have been of benefit.

5. Overall recommendation

Firstly, a cost benefit analysis should be undertaken to determine whether the costs associated with the development of the visualisation will add value to the representation of the delay claim. This was overlooked in this case study, which resulted in neither visualisation being used as a supporting tool. Despite this, the case study identifies the potential benefits of using visualisations and that the problems encountered can be mitigated.

In future, if visualisations are used to support construction delay claims, it is recommended that they have a side by side comparison of as-planned and as-built progress which is linked to a construction programme, as promoted by Pickavance (2007). Ideally, an accurate 3D visualisation would be developed of all the main construction works on the site, including the main resources used in its construction. Therefore, if simultaneous delays occur, multiple views of the project can be represented in different windows to see the effect of the delay on the entirety of the project. Supporting information could then be coordinated and linked to the model to add clarity. With the rise of BIM, software packages are becoming available which offer these services in a bid to support the new process of working.

Regardless of the capabilities of the software, the case study highlights the importance of strong communication between all parties in order to provide a visualisation which effectively represents the delay analysts findings. Given the justification for this research, 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. Preferably, a delay analyst with virtual modelling skills would be employed to create the visualisation, or visa-versa. If not, as is always the case where different professional disciplines are required to work together to produce a solution, strong communication between both parties is required to ensure the visualisation conveys the delay findings as accurately and effectively as possible.

In order to assist the research, further case studies should be undertaken in which a visualisation are used and the recommendations identified in this paper should be incorporated on a delay claim using visualisation and reported on.

6. Conclusion

One of the challenging tasks faced by delay analysts is to clearly represent their findings to support a construction delay claim. The traditional methods of representing construction delays through construction programmes can be difficult to understand, as highlighted by the case law, and assistance through technological developments in computer generated visualisations is recognised.

The potential to use visualisations to support construction delay claims is discussed through an in-house case study where two different visualisations, one in 2D and one in 4D, were developed to assist with the same delay claim. Despite neither of the visualisations being used to support the delay claim, the research highlights some important findings. These include the need for a cost benefit analysis before a decision is made on whether to use a visualisation to support a claim, the importance of a linked logically driven construction programme to the visualisation as well as a side by side comparison of as-planned v. as-built progress. Given the justification for the research, as with any project, the importance of strong communication is required in order for the project to succeed. Further research is required to put the recommendations found in this paper into practice to demonstrate how they can support a construction delay claim. The potential to exploit elements of BIM to assist with construction delay claims are also discussed to assist with construction claims and will continue to be researched as part of an engineering doctorate.

References

Arditi, D., & Pattanakitchamroon, T., (2006) Selecting a delay analysis method in resolving construction claims. *International Journal of Project Management*, **24**, 145-155.

BCIS., (2012) Construction Tender Price Indices.

Bouchlaghem, D., Shang, H., Whyte, J., & Ganah, A., (2005) Visualisation in architecture, engineering and construction (AEC). Automation in Construction, **14**, 287-295.

Braimah, N., & Ndekugri, I., (2008) Factors influencing the selection of delay analysis methodologies. *International Journal of Project Management*, **26**, 789-799.

Bubshait, A., & Cunningham, M., (1998) Comparison of Delay Analysis Methodologies. *Journal of Construction Engineering and Management*, 315-322.

Cabinet Office., (2011) Government Construction Strategy. May 2011.

Card, J., Mackinlay, B., & Shneiderman, B., (1999) *Readings in Information Visualization: Using Vision to Think*. San Francisco: USA, Morgan Kaufmann.

Carnell, J., (2000) *Causation and delay in construction disputes*. Oxford, England: Blackwell Science.

CIOB., (2008) Managing the Risk of Delayed Completion in the 21st Century.

Cooke, B., & Williams, P., (2009) *Construction Planning, Programming and Control 3rd ed*. West Sussex, England: Wiley-Blackwell.

Dziurawiec, S., & Deregowski, J., (1986) Construction errors as key to perceptual difficulties encountered in reading technical drawings. *Ergonomics*, **29**(10), 1203-1212.

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, New Jersey: John Wiley & Sons.

EC Harris., (2012) Global construction disputes 2012: Moving in the right direction.

Farrow, T., (2001) Delay Analysis – Methodology and Mythology. *Society of Construction Law*.

Fenwick Elliott., (2012) Dictionary of Construction Terms. Edited by: Tolson, S., Glover, J., and Sinclair, S. Informa law.

Ganah, A., Anumba, C., & Bouchlaghem, D., (2001) A survey on the use of visualisation tools to communicate buildability information. *COBRA conference*.

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

Greenwald, N., (2012) A creative proposal for dispute systems design for construction projects employing BIM. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*. Posted ahead of print.

HM Treasury., (1999) Benchmarking the Government Client - Stage Two Study. Constructing the Best Government Client.

Keane, P., & Caletka, A., (2008) *Delay Analysis in Construction Contracts*. West Sussex, England: Wiley-Blackwell.

Kumaraswamy, M., & Yogeswaran, K., (2003) Substantiation and assessment of claims for extensions of time. *International Journal of Project Management*, **21**, 27-38.

Narayanan, A., & Hibbin, S., (2001) Can animations be safely used in court? *Artificial Intelligence and Law*, **9**, 271-293.

NBS., (2012) National BIM Report.

Parent, R., (2012) *Computer Animation Algorithms & Techniques 3rd ed*. USA: Elsevier.

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.

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

Sacks, R., Eastman, C., & Lee, G., (2004) Parametric 3D modeling in building construction with examples from precast concrete. *Automation in Construction*, **13**, 291-320.

Schofield, D., Hussin, N., & Shalaby, M., (2005) A Methodology for the Evidential Analysis of Computer-Generated Animation (CGA). *Proceedings of the Ninth International Conference on Information Visualisation (IV'05)*.

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

Sweet and Maxwell., (2010) Construction disputes leap by almost a third during the credit crunch.

Tizzard, A., (1994*) Introduction to Computer-aided Engineering*. England: McGraw-Hill.

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

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

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.