An interactive exhibit to assist with understanding project delays

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Abstract

Time, a dynamic concept, can be difficult to understand in static form. As a consequence, the pro-active 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 which could develop into dispute if they are not resolved. Disputes have a negative effect on the construction industry but their occurrence, value and duration is rising. This research aims to reduce the likelihood and severity of common delay disputes by providing a solution which aims to: 1) assist with the pro-active management of delays; and, 2) improve the presentation of delay claim information. A detailed background study was undertaken which identified technological opportunities and modes of presentation as potential ways of overcoming the challenges associated with managing and analysing delays. Two stages of assessment were then undertaken to determine the suitability and application of these findings. The first stage utilised 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, which was assessed through a simulation based on case study data. The interactive exhibit is intended to support, not replace, traditional methods of delay analysis but the solution encountered difficulties with technology as well as the challenge of creating a holistic tool for both pro-active management and retrospective analysis. It is perceived that the interactive

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exhibit would add most value to the resolution of construction delay claims but further investigation is required to validate the proposed concept before it is used in practice.

Key words

4D; BIM; Claim; Delay; Dispute; Evidence, Extension of Time; Modes of Presentation; Pro-active control; VARK.

Introduction

Over 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, 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):

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

This research aims to reduce the likelihood and severity of disputes by providing a holistic solution to the common causes. This includes:

1. assisting with the pro-active management of delays so appropriate control action can be taken and interim awards of extensions of time can be granted; and,
2. 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 could assist the current legal environment. As 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, 2014) to produce a concept which integrates modes of presentation with delay analysis. The output was an interactive exhibit, which 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 could 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 are undertaken before the concept is used in practice.

Background

Managing time and analysing delay

The term "delay" can be defined as the non-completion of works by a date agreed in the construction contract (Fenwick Elliott, 2012). A delay event could occur for a wide-range of reasons (Ramanathan, 2012) and could affect project progress or project completion (SCL, 2002). A construction programme, 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, 2014). It is recommended that the construction programme is produced using 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 which are delayed on the critical path will extend the project duration and there may be parallel, or near critical, paths on a project. Therefore, due to 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 programme is continually updated and revised as more accurate and detailed information becomes available, which includes impacting change events into the programme (CIOB, 2011). Delay can still occur if this good practice is followed, but the pro-active approach should allow the effect of change to be realised 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 pro-active management may not produce the information required for retrospective analysis (Scott, 1990). As a consequence, if the effect of a change event is not analysed contemporaneously, a retrospective delay analysis may be required.

A delay analysis forensically investigates the issues which 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 which can yield different results, even if the same methodology is used (Braimah, 2013).

The legal system leans towards the use of construction programmes, particularly the use of the critical path method, for delay analysis (Bayraktar, 2012). A plethora of different titles exist for the types of delay analysis (AACE, 2011) and there is no preferred method, but some of the recognised methods can be categorised as (SCL, 2015):

- as-planned v 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, 2006) but the chosen methodology will be influenced by a variety of factors, most notably the factual material available (Braimah, 2008). Not all of these methods are recognised as appropriate for both pro-active 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, 2004). This classification can influence how delay is communicated.

The time impact analysis is identified as a sophisticated methodology which can be used for both pro-active management and retrospective analysis of delay (CIOB, 2011). This methodology involves (SCL, 2002):

1. bringing the programme up to date before the delay event occurs and correcting incorrect logic and durations;
2. modifying the programme to reflect achievable plans and any recovery action to be taken;
3. impacting the delay event into the programme; and,
4. 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 are 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 of the delay analysis methods. This involves dividing the programme into logical segments and analysing the impact of delay in each segment (Pickavance, 2010). However, even if this approach is used, the claim might still not be understood or agreed, so it could be rejected and 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, 2010).

A dispute occurs when a claim cannot be resolved but 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 if the change did not occur (*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, 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, 2011). This will depend on the available facts and how they are presented (Gibbs, 2013), with preference to neutral, contemporaneous records (Kangari, 1995).

The recoverable damages will be subject to remoteness and how the delay is categorised, which is dependent on the contract and the claiming party (Figure 1).

< Figure 1~~FIGURE 1~~ >

Delay claim challenges

Previous research identified that two challenges associated with analysing delay are the retrieval of information to perform the analysis and the communication of the findings (Gibbs, 2013). Attempts to address the retrieval of delay claim information are presented in the literature (Alkass, 1995) and developments in electronic document management systems should, in some way, assist with addressing this challenge. However, little research is published which investigates how to improve the communication and understanding of the cause and effect of delay to support pro-active decision making and retrospective analysis.

Although it may be simple for a claim to originate, communicating and agreeing 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, 1995).

Conventionally, construction delay claims are paper intense and consist of a claim report narrative, construction programmes and supporting evidence. However, these modes of communication are not always appropriate because time, a dynamic concept, can be difficult to understand in static format (*Balfour Beatty Construction v. Lambeth London Borough Council*).

Under the current process, users must conceptually associate 2D drawings with the related project tasks to form an image of what occurred on the project (Koo, 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, it 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 utilise technology (Narayanan, 2001; Feigenson, 2011; Schofield, 2011).

Use of technology in the legal sector

The legal sector tends to be risk averse, so any technology which is adopted by legal service providers is required to go through rigorous analysis and review to ensure it is correctly utilised and fit for purpose. Client demands, competitive pressure and the recession have prompted law firms to increase IT use but investment in technology by the legal sector still remains lower than other industries (LSN, 2015).

In an attempt to improve efficiency, the UK criminal justice system is going through a process of digitisation. The aim is to reduce the heavy reliance of 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 in-court digital evidence, such as video links with witnesses and the clear display of evidence directly to the court from an advocates 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 could be harnessed to improve the communication of delay events. To develop a feasible solution, appreciation was given to the digital tools and processes which are becoming commonly used on construction projects (BIM and 4D modelling). The ability to use the available digital outputs as evidence in the highest legal setting, the courtroom, was explored (computer generated exhibits) as well as the opportunity to enhance understanding through technology (interactive videos) and the science behind communication (modes of presentation).

4D modelling

4D modelling is the process of linking a construction programme to a 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 modelling. However, access to object orientated 3D virtual models has increased following the uptake of Building Information Modelling (BIM) on international construction projects (NBS, 2014). This provides a platform for 4D modelling and the opportunity to harness recognisable 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, 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, 2000). Coupled with the appropriate skillset, 4D modelling could be used for effective communication to foster productive discussions for pro-active management or within the early stages of different forms of alternative dispute resolution (Wing, 2016). However, while BIM and 4D modelling could assist with reducing the likelihood and severity of some disputes, they will not eradicate disputes within the industry and the new processes of working and ways of communicating information could unveil different forms of dispute (Gibbs, 2015; Olatunji, 2016).

Computer generated exhibits

Demonstrative evidence, in the form of computer generated exhibits (CGE), 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, 1997). These CGE's can be classified in increasing probative value as (Burr, 2010):

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
4. Evidential: A different way of demonstrating primary evidence

However, construction delays have experienced little advancement in technology (Vidogah, 1998) and only a small amount of research discusses the practical application of CGE for construction claims (Pickavance, 2007). To avoid affecting the admissibility of CGE's as evidence, emotive content such as manipulating camera angles and adding special effects should be avoided (Schofield, 2011). Further research into this field is required (Feigenson, 2003) but in an attempt to overcome these challenges and encourage CGE use, recommendations on the creation of CGE's for the pro-active control and retrospective analysis of delay have been published (Gibbs, 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-panned and as-built CGE's with timeline; and,
- ensuring communication between the creators of the programme and the virtual modelling organisation.

Interactive videos

While visualisations can increase intuitive perception, data can be better evaluated and alternatives analysed if the viewer is able to interact (Pensa, 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 the viewer clicks the tag they can access more information about an item and influence the flow of the video (Stenzler, 1996).

This concept has been utilised by the advertising industry but the benefits could assist with education because it improves understanding through the incorporation of different modes of presentation within 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. The capacity of the working memory is limited and temporarily stores information to be organised, this is where an audience holds their attention (Clark, 2008). The new information is then integrated with existing knowledge to form long term memory and understanding (Mayer 2009).

The ability to integrate this information can depend on how the material is communicated. VARK modes of presentation, whereby each of the acronym letters are described below, identify that individuals learn in different ways and can have preference to one of the following (Fleming, 1992; Leite, 2009).

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

Preference to a mode of presentation is not specific to a certain type of job. For example lawyers, who might be perceived to learn through Read/Write, actually have diverse learning styles (Boyle, 2005). A combination of presentation modes may be advantageous to some individuals (Mayer, 1991; Fleming, 1995) whilst improving the satisfaction of the task (Sung, 2012). However, in some instances, individuals can report fragmented or even no learning because the working memory is overloaded with processing irrelevant information (Mayer, 2001). To combat this, regular pauses are recommended

(Spanjers, 2012) and rules and guidelines have been developed for the presentation and interaction of information (Baldonado, 2000).

Methodology

This research investigates if the communication of project delays could be improved by incorporating different modes of presentation into available technology. As no literature was found which identifies whether and how VARK modes of presentation could 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 could be applied in the industry through a simulation.

Workshop

Expert opinion was sought to determine the feasibility of using modes of presentation to improve the 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 workshop was held with fifty practicing Royal Institute of Chartered Surveyors (RICS) adjudicators for thirty minutes.

Adjudicators were chosen as they regularly encounter the challenge of understanding construction claim information and although their appointment indicates a dispute, their experience offers a useful insight 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 fifty RICS adjudicators were presented with background information on the challenge of representing construction delay information, the rise and perceived benefits of CGE and details about learning styles. CGE, for the purpose of the workshop, was described as the use of a computer to generate static or dynamic imagery of tangible construction operations and excluded construction programmes, photographs and videos.

An example CGE was presented in the workshop to demonstrate how it was used to support a claim (Figure 2). This CGE used graphs, 2D site layout and animations to show the process of casting, shipping, storing and installing concrete segments for the construction of a viaduct. The Visual components demonstrated that the works were out of sequence and the impact it had on the project. Aspects of Kinesthetic learning were incorporated into the CGE as the user was able to increase speed, filter information and access further information through interaction.

< Figure 2~~FIGURE 2~~ >

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 were recorded and promoted discussion which was captured and is 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 could be incorporated into delay analysis.

Given the legal sectors need to rigorously test new technology before use, simulations were chosen as they avoid the risk of failure on a live project by creating and testing a concept in a synthetic environment (Wieringa, 2014). Although there will 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 to the context it was intended (Zelkowitz, 1998). Therefore, to establish a realistic environment for testing, data was obtained from a case study of a construction dispute.

Case studies allow complex problems to be explored within a real-world 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, multi-story office building. Empirical data was obtained from claim consultants but due to 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 represents a concrete frame contractor who was required to follow a mandatory sequence of works (Figure 3). One of the principal delay events which contributed to the 147 days delay to the agreed practical completion date was slow progress by the steelwork contractor.

< Figure 3~~FIGURE 3~~ >

A time impact analysis with one month windows was used to analyse the delay on the project. The delay analysis consisted of over 3,500 interconnected activities and although this approach provided a detailed mathematical analysis, it made understanding the cause and effect of delay challenging.

Incorporating 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 different modes of presentation with the delay analysis as well as current and past research findings, using a variety of software packages (Figure 4).

< Figure 4~~FIGURE 4~~ >

To create a fact driven 4D model of the delay claim, a 3D model and the construction programme were required. The original delay analysis was produced in programming software which 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 which allowed it to be imported into the construction sequencing software. Checks and modifications were undertaken to ensure an exact replica of the analysis was presented.

A 3D model of the project was not available and had to be created using object-oriented software. The 3D model was produced using technical drawings, design information and photographs which were provided to the claim consultants. The 3D model was imported into the construction sequencing software and the activities in the programming software were linked to the 3D objects. Appropriate camera angles and visualisation 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 summarised the report narrative, was recorded in the video creating software to describe what was occurring on screen. The Visual and Aural recordings were performed 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. The length of the text was limited so it did not 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 which contained additional information such as photographs, videos, graphs and more detailed and cross referenced text description.

Suitability of proposed concept

Workshop findings

At the time of the workshop, the fifty participants accounted for 50% of the individuals registered on the RICS panel of adjudicators. The data obtained from the workshops structured questions are presented in Table 1.

< Table 1~~TABLE 1~~ >

The workshop participants stressed that a CGE should only display fact and that the information driving the Visual should be visible to the viewer. To determine the value of CGE, some participants indicated a preference to interrogate the exhibit but the necessity of this split the workshop. The majority of participants commented that interrogation was not fundamental and, in its most basic form, the CGE could be used to give an overall impression of a claim. It was stated by a participant that this would be advantageous in adjudications, where an adjudicator has a short duration to understand a dispute and report their decision. However, some participants indicated that although CGE's may be visually appealing and useful in swaying a jury, there will always be an element of doubt that it is accurately reflecting the facts.

There was a common consensus amongst the participants that it is the responsibility of the CGE's creator to tell the viewer how it can be relied upon. Furthermore, there was a general agreement that the CGE should be kept as simple as possible and include sufficient explanation to communicate what is occurring on the screen. The participants recommended showing actual progress against what was planned and using video and pictures as supporting evidence. It was also stated in the workshop that the CGE could be useful to pro-actively 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 CGE's 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 will depend on its purpose. It appeared that the workshop participants were unaware of the different degrees of CGE value which may have contributed to the divided response on the appropriateness of CGE's as supporting evidence. Therefore, the use of a narrative to explain how the viewer can rely upon the CGE would be of benefit.

There may be a lack of confidence in CGE's due to 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 could be provided to allow interrogation of the model.

Nevertheless, the value of including all modes of presentation into the CGE was recognised by the majority of participants. Nearly the entire workshop agreed that enhancing Read/Write functions and adding Aural narration to the existing Visual and Kinesthetic modes of presentation in the CGE would have improved its value.

Given the professional status and the sample size of the population, the findings indicate that modes of presentation could improve the understanding of construction delays and, if used correctly, technology is 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 workshops findings and the recommendations found in related literature (Gibbs, 2014), as outlined in Table 2~~Table 2~~.

< Table 2~~TABLE 2~~ >

These recommendations are applied and described in the figures below, for specific times in the interactive exhibit, to demonstrate how the slow progress of the steelwork contractor caused delay to the concrete frame contractor during one window of analysis.

< Figure 5~~FIGURE 5~~ >

00min 01sec	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.

< Figure 6~~FIGURE 6~~ >

00min 50sec	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 to assist with differentiation. Concrete contractor works are coloured blue and steelwork contractor works are coloured green.

< Figure 7~~FIGURE 7~~ >

01min 06sec	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, which make the video interactive.

< Figure 8~~FIGURE 8~~ >

01min 06sec	When the tag is clicked the exhibit is paused and a box containing additional information, such as pictures, videos or text reference to the report narrative, is displayed. If the tag is not clicked, the exhibit progresses as normal.

< Figure 9~~FIGURE 9~~ >

02min 39sec	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 ensure the integrity of the dealy 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 conceptualisation 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 are summarised and their benefits and limitations are presented in Table 3~~Table 3~~.

< Table 3~~TABLE 3~~ >

The development of the 4D model demonstrated the need for consistency between the granularity of the virtual model and the construction programme. This is easier to achieve, but less useful, if undertaken retrospectively. Nevertheless, communication between the individual creating the programme and the 4D model developer is critical and an appreciation of the different disciplines would be beneficial, otherwise problems could 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 programmes 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 uninfluential 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 imported into the construction sequencing software as required, the delay analysis did not have a direct interface with the construction sequencing software. As a consequence, the native delay analysis file was transferred through different programming software packages to create a compatible file format. This resulted in the distortion of data, so alterations and checks were necessary to ensure consistency with the native file. This was a timely process so to reduce doubt about the integrity of the analysis, the summary box at the end of the exhibit compares as-built photographs with the virtual model.

Once the Visual aspect of the model was developed, the video creating software made the incorporation of Read/Write and Aural modes of presentation straightforward. A soundtrack was not included in the exhibit as it could distract the viewer and slower speech and regular pauses were incorporated to allow time for the 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, the Read/Write and Aural descriptions were limited and if any additional information was required, it could be achieved by clicking on the interactive tags. The information behind the tags might not offer the required level of information to support a claim; therefore, a report narrative should still be provided with the appropriate detail.

Nevertheless, the clickable tags promote Kinesthetic learning through user interaction. This style of learning could be enhanced by viewing the interactive exhibit on a mobile device, which would allow the viewer to understand information away from their desk. This option is supported through private online access; however, this requires the data to be held on a third party sever. This could form a barrier to adoption but it is anticipated that alternative ways of creating and viewing interactive exhibits will become available in the future.

Given the nature of video, Visual is the primary mode of presentation for the exhibit and the other modes of presentation provide secondary support. As it is impossible to interact all senses with digital technology, incorporating Kinesthetic modes of presentation into the delay analysis posed the greatest challenge. Furthermore, a video was required to support Aural and Read/Write modes of presentation in the delay analysis. This removed the ability to interrogate the delay analysis in a 4D environment, which would have benefited Kinesthetic learning. Therefore, a native file of the 4D model could be provided in addition to the interactive exhibit to allow for interrogation and enhanced Kinesthetic learning.

The time impact analysis demonstrates how the modes of presentation could assist with pro-active control and retrospective analysis. However, the interactive exhibit appears most suitable for construction claims.

The resources required to produce the interactive exhibit for pro-active control may outweigh the overall value gained. Pro-active 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 as the individuals 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 the time and resources could be better focused on overcoming delays than reporting their effects in the form of an interactive exhibit. However, the Visual concept of side by side comparison of as-planned and as-built 4D models could, in isolation, be utilised to pro-actively manage delays.

Overall, the interactive exhibit could address some of the challenges individuals face when trying to understand the effects of delay. The various modes of presentation should enhance understanding for an individual with limited project or delay knowledge. This can improve the clarity of the claim and could shift the balance of probabilities in the party's favour. Thus, it could 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 the understanding of delays for pro-active control and retrospective analysis. Taking into account the level of IT use in the legal sector, a practical solution was developed through two stages of assessment.

The first stage confirmed the suitability of using modes of presentation to improve the understanding of construction claims and gathered requirements for future development. In line with the literature, the industry experts identified that CGE's are not common forms of evidence for construction claims (Vidogah, 1998) and when CGE's have been used to support claims, they have not always been helpful. The expert's suggestions for improvement were consistent with previous research (Gibbs, 2014) and their concerns mirrored some of the issues presented in the literature (Schofield, 2011). This included informing the viewer how they can rely on the CGE, as not all individuals are familiar with the different categories of CGE's (Burr, 2010). If this is not communicated, it could cause the CGE's integrity to be questioned and this could be exasperated if the CGE cannot be interrogated. For avoidance of doubt, it is recommended that the native 4D file is made available so the data can be independently analysed if required. The integrity of the CGE as evidence could be assisted by the inclusion of modes of presentation and could be used to explain and cross reference what is occurring on the screen.

The second stage developed the workshop findings and demonstrated that all four modes of presentation could be successfully integrated into an interactive exhibit; however, this was not without its challenges. Integrating the different modes of presentation evenly into the CGE was restricted by technology. In the proposed concept, the Visual mode of presentation appears to be the primary mode, with the other modes attached. Therefore, some of the perceived benefits of the interactive exhibit might be attributed to the side by side comparison of as-planned and as-built progress. Further challenges included the interoperability issues. Literature on the interoperability issues for 4D modelling is lacking and while this research goes some way to demonstrate the challenges, additional research into software interoperability and the granularity of detail for the simultaneous production of programme and 3D virtual model is required.

The time impact analysis demonstrates how the proposed concept could be used for both pro-active control and retrospective analysis but the research exemplifies the challenge of creating a holistic tool (Scott, 1990). It is perceived that the interactive exhibit would add greatest value to construction claims because it can assist with communicating causality, responsibility and quantum in its clearest form. This is consistent with literature associated with the applicability of 4D modelling, which identifies the greatest value of 4D modelling is to those with a lack or site related knowledge (Mahalingam, 2010). Therefore, the interactive exhibit could improve the standard of evidence and tip the balance of probabilities but further research is required to test the concept in practice and additional value could be gained through analysis on non-linear projects with different methods/classifications of delay analysis which require different levels of communication (Ng, 2004). Further research is also required to determine the added value of the interactive exhibit for pro-active 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 about project delay through modes of presentation. It is suggested that the interactive exhibit is used as a supportive tool and not as a replacement for conventional methods but before the proposed concept is incorporated into practice, additional stages of assessment should be undertaken.

Acknowledgements

This research was supported by the Engineering and Physical Sciences Research Council (EPSRC). Further acknowledgement is extended to Arbrix and the workshop participants as well as the claim consultants who provided data and resources for the research. Acknowledgement is also given to the reviewers for their comments which have helped shape this article.

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Figure captions

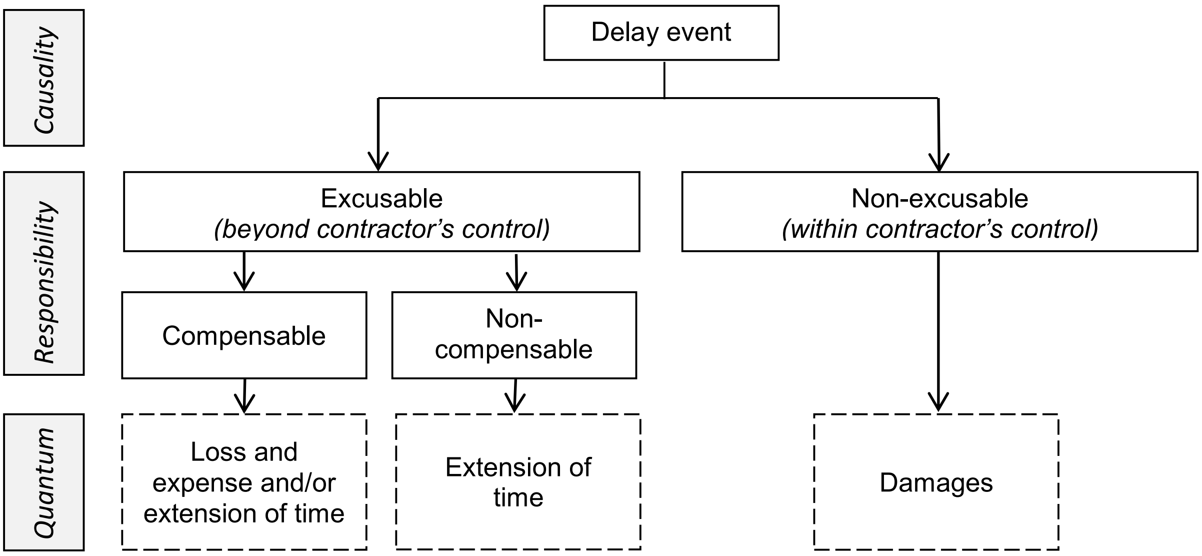

Figure 1. Generalised interpretation of the categories of delay (adapted from Trauner, 2009)

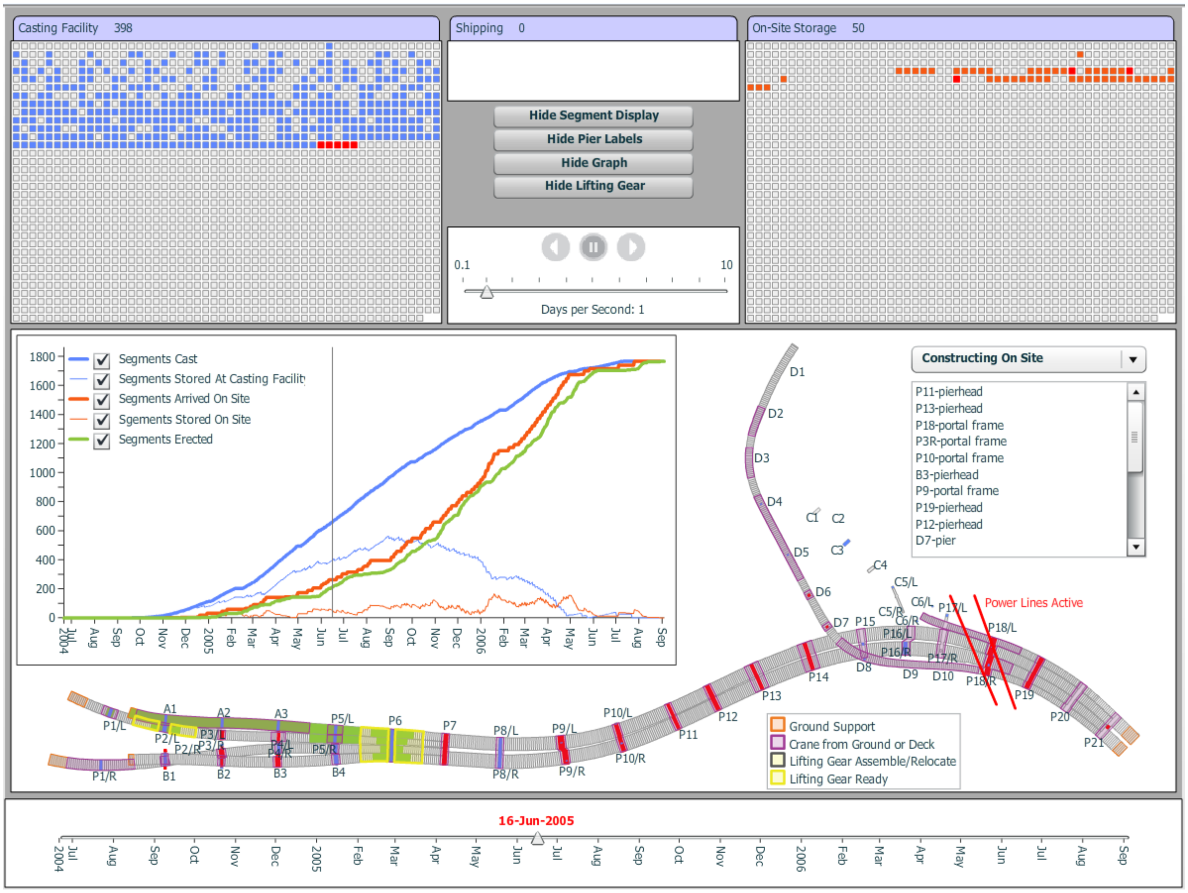

Figure 2. CGE used to support a delay and disruption claim on the construction of a viaduct

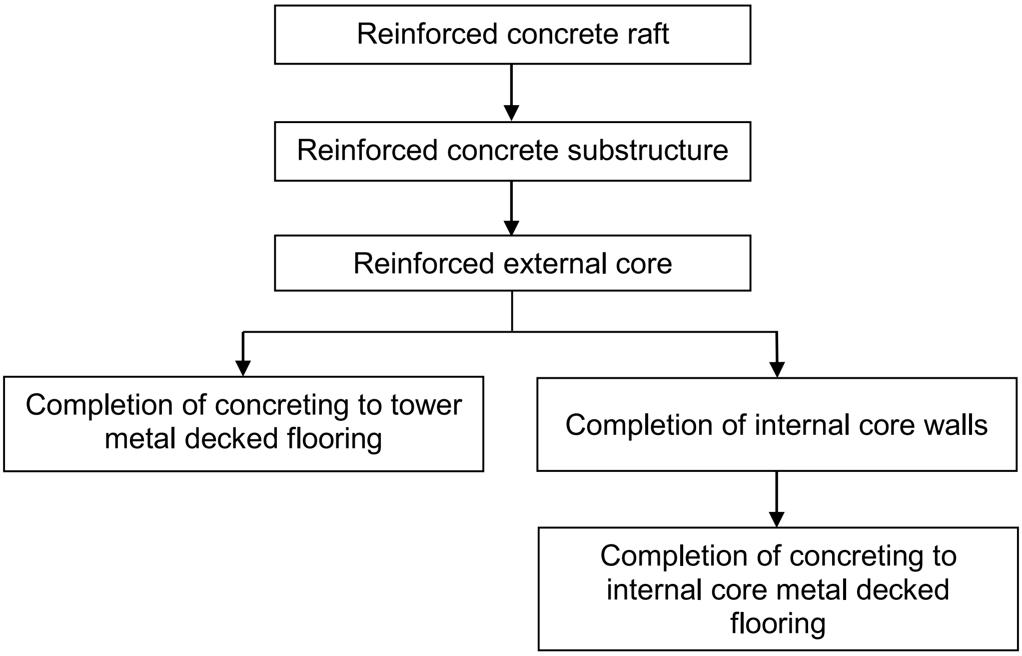

Figure 3. Concrete frame contractors mandatory sequence of works

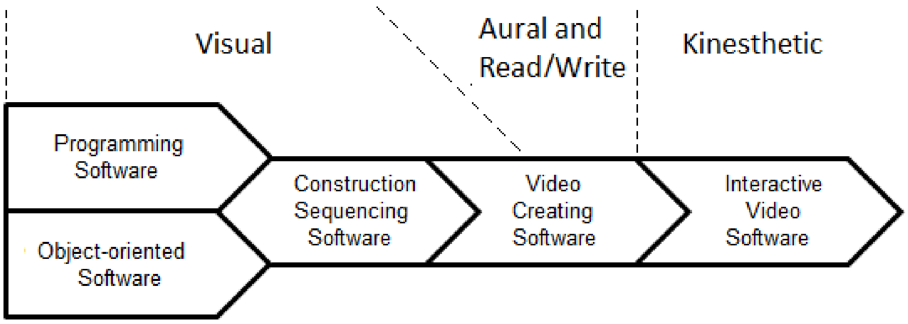

Figure 4. Software used to develop each mode of presentation

Figure 5: Interactive exhibit at 00:01

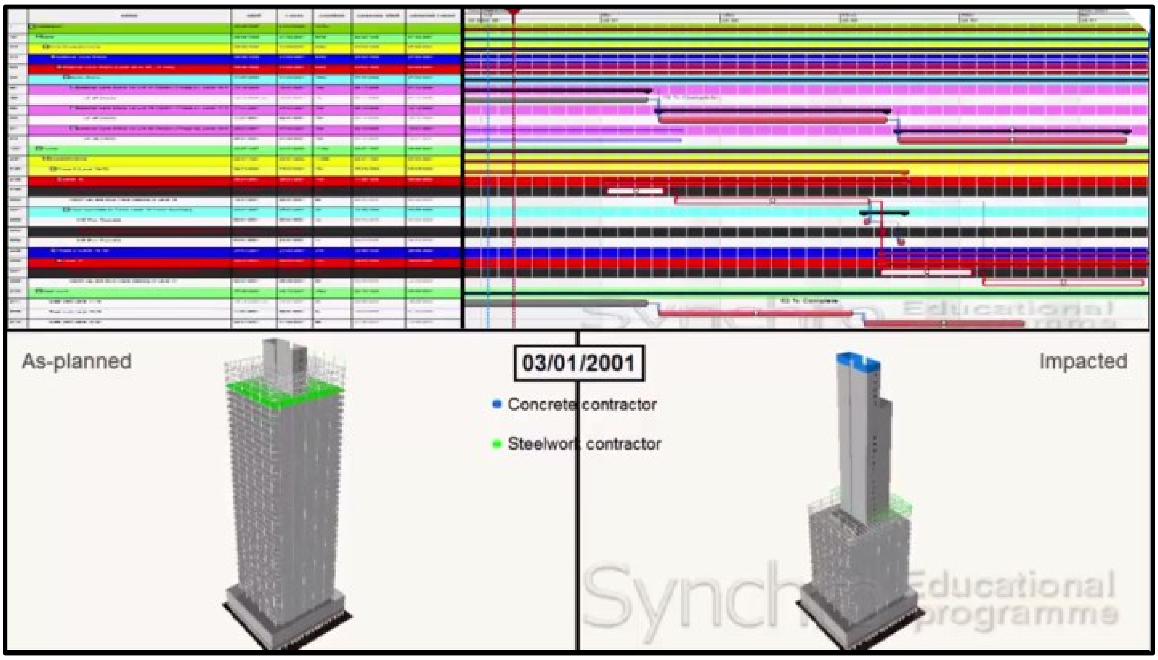

Figure 6: Interactive exhibit at 00:50

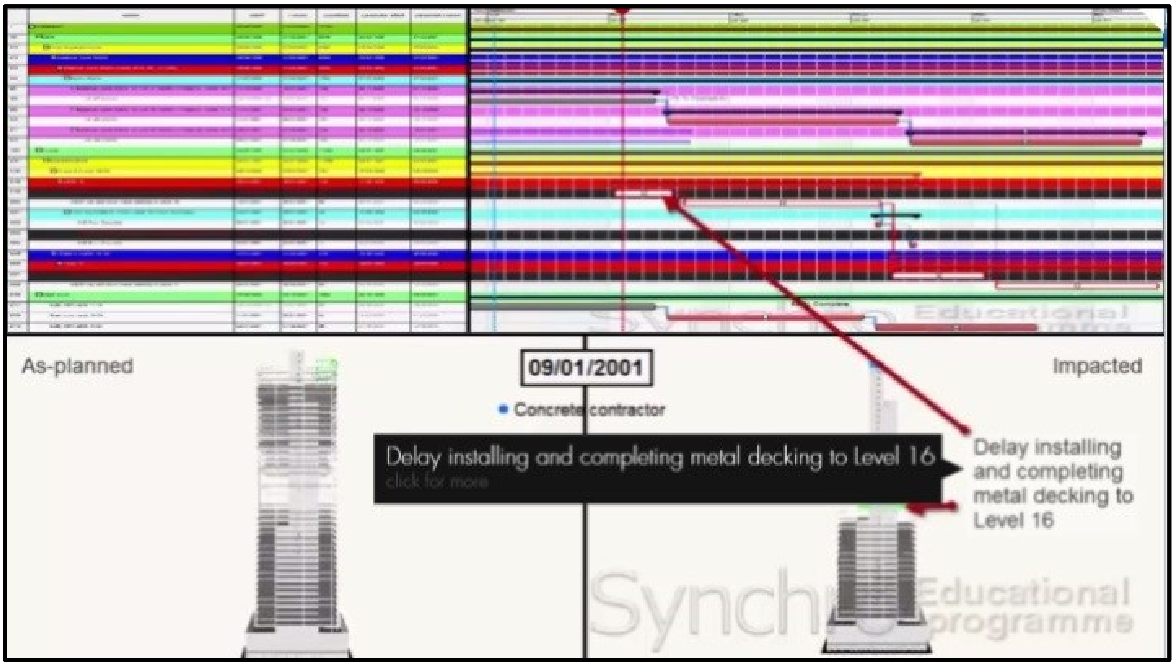

Figure 7: Interactive exhibit at 01:06

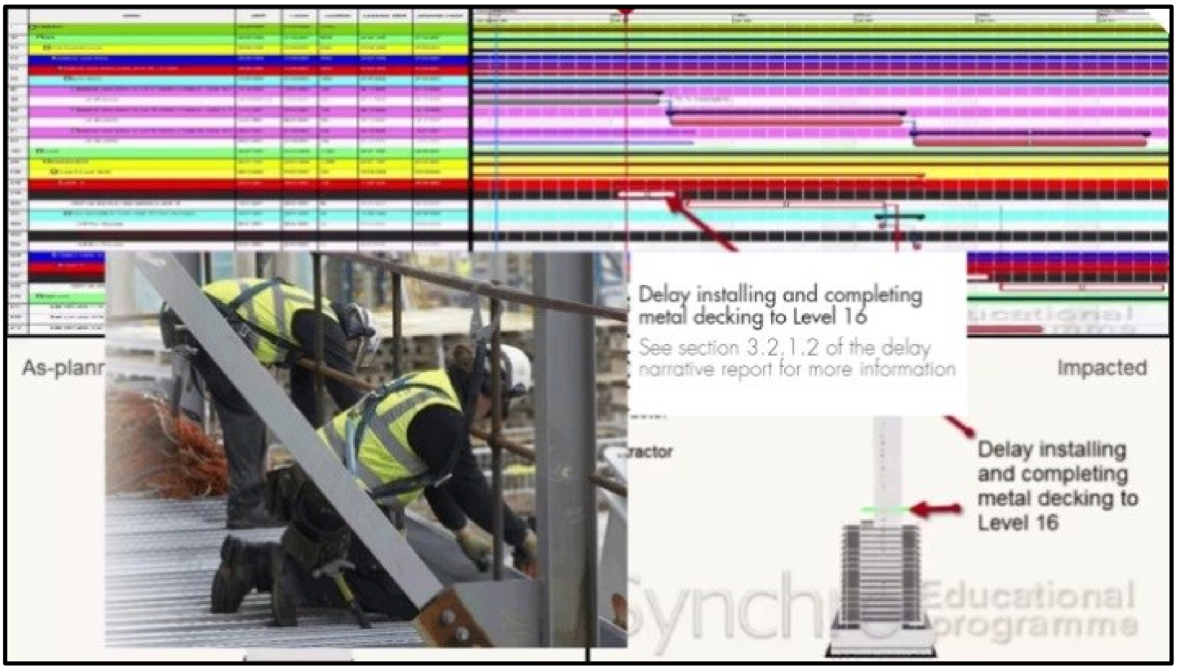

Figure 8: Interactive exhibit at 01:06 (interactive tag clicked)

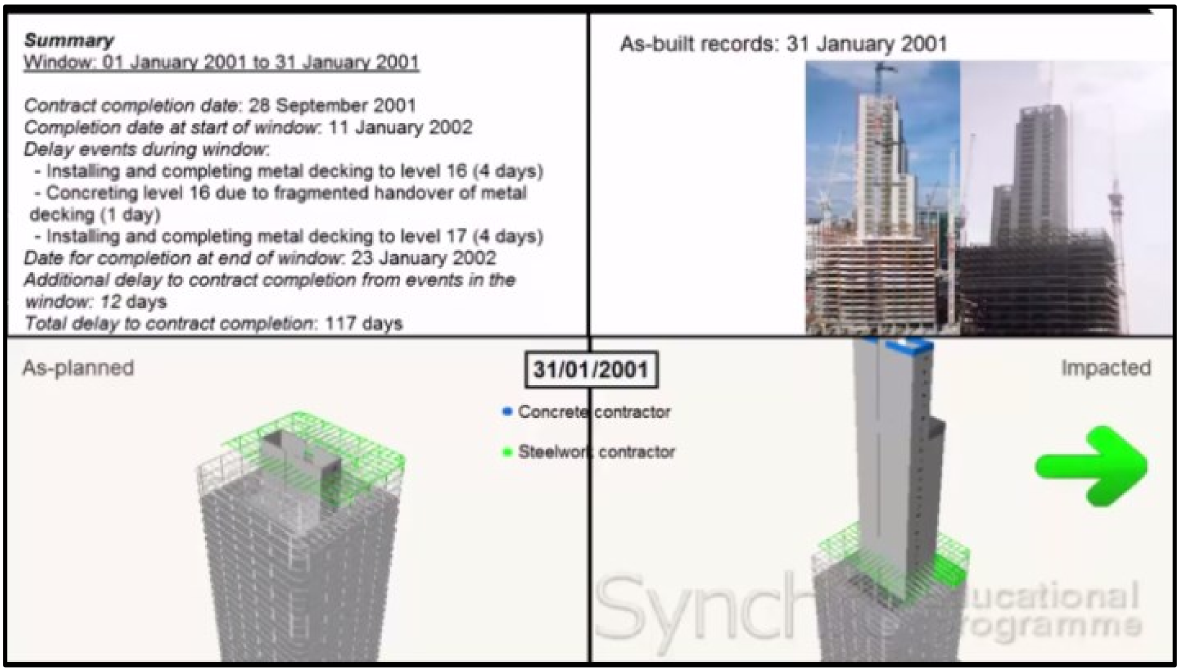

Figure 9: Interactive exhibit at 02:39

Tables

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%

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.

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.