UNIVERSITY OF CAMBRIDGE

Transforming construction: impact case study

Benefits to industry: improved project communication and decision making; higher productivity

Taking note: improving visualisation of data in BIM for better decision making

Inefficient information sharing is a significant contributor to the construction sector's productivity gap. While other sectors have digitally transformed to secure associated benefits, the construction industry's evolution continues to be slow; according to the McKinsey Global Institute (MGI) Industry Digitisation Index, construction remains one of the most undigitised industries in the world[1]. Additional contributing factors to the productivity gap include management difficulties, supply chain issues and rework. Research analysing supply chains reports cost increases of 40 to 250 per cent of the purchase price to remedy extra work due to incomplete information.

Current challenges

One factor interrupting efficient dissemination of information is that inputs are often not ready when required. Disconnected documents, drawings and other files ('data') first have to be combined into a 'mental model' (a visualisation of the end result) to make them comprehensible and actionable, resulting in significant processing times during which workers and suppliers are waiting for instructions. In addition, due to the variety of stakeholders involved, multiple interpretations of the various sources of information exist. Because of preference for individuals' own personal mental models, decision makers tend to ignore the interpretations of other stakeholders resulting in a waste of time, miscommunication, project execution problems and, consequently, low productivity.

Optimising BIM efficiency

Building Information Modelling (BIM) has been identified as a technology to improve dissemination of information and is integral to digital transformation across the built environment. The UK Government Industrial Strategy sets out plans to increase productivity in construction to deliver £1.7 billion efficiencies. BIM and digital construction are identified as key components of the strategy. Government mandated BIM for all centrally procured Government contracts from 2016 driving industry implementation of BIM and supporting a wider offsite manufacturing strategy.

[1] www.mckinsey.com/industries/high-tech/our-insights/digital-america-a-tale-of-the-haves-and-have-mores

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This case study suggests BIM has not yet been exploited to its full potential and proposes a new notation for visualising project information in a BIM context. The addition is inspired by music and dance notation, and is designed to overcome current limitations that may discourage the technology's use during the construction phase.

Data sharing on projects

Construction firms have adopted a variety of tools and methods in an attempt to improve data sharing on projects. BIM, project and document management software, 4D simulations and visualisation tools are in use throughout the industry.

New methods such as lean production management and (advanced) work package management are being introduced with varying levels of success, but finding and using data inputs for all of the elements comprising a Scope of Work is a time-consuming activity that remains largely unsolved. BIM could provide context to limit the interpretation effort but use currently focuses on coordination of design and engineering inputs. Data enclosed in BIM elements remain mostly unused during construction. 4D BIM visualises construction planning data but requires significant amounts of non-productive time for linking of 3D geometry to tasks. Adopted tools are deployed to solve specific business problems but fail to address the issue of disconnected data.

Proposed solution

Addressing the currently existing gap between BIM tools and desired support for decision making to improve productivity requires a solution that facilitates access to project data in a BIM context. Users of current solutions must navigate 3D models and select individual elements in current BIM tools to access data with results presented as properties of selected elements. However, supervisors and engineers make decisions based on data related to multiple elements typically associated with a location or a task. Therefore, a new solution is needed to provide access to a summary of relevant data in a specific location or for a specific task. Requirements for the proposed solution are:

- requirement A: automated association of BIM elements with project data for locations and tasks
- requirement B: automated location, project phase and role assessment to determine what data should be presented to supervisors and engineers
- requirement C: a notation for BIM that summarises and communicates data relevant for current locations and tasks.

The proposed solution combines the lean production concept of 'make ready' work with BIM. Lean production 'make ready' work requires that project teams ensure availability of all needed inputs for a unit of work before its planned start.

Taking note

The focus of this research was on requirement C and resulted in a new BIM notation inspired by music and dance notation. These notations present 'note' and 'movement' symbols on a timeline that uses markers for 'meter' (or 'beat'). Musicians and dancers read notations by following the beat in performed music. The approach of markers for main units on a timeline is adopted for the BIM notation. However, contrary to music and dance, the BIM notation uses a logarithmic time scale with days, weeks and months replacing music's beat because project teams work towards weekly, monthly and annual delivery milestones. A nonlinear time scale is chosen to enable status updates and forecasts beyond the current week and to provide input for longer term preparation work. The notation presents status information for contract documents, design, schedule, material deliveries and QA checklists: key aspects chosen after analysis of a completed project's management data. Aspects are placed on a horizontal 'staff' similar to music notation and assigned a dedicated 'lane' similar to dance notation. Coloured symbols for selected aspects indicate current and forecasted status and potential downstream impact of risk to allow for review of readiness when preparing for scheduled work in a location. The notations present a summary of relevant data associated with the collection of BIM elements in a location to eliminate the need to examine individual elements. See Figure 1.

Applying the methodology

The value of the proposed solution for requirement C was tested in an experiment in which response time and accuracy for a series of 10 questions was measured. Designed questions were asked from subcontractor perspective related to status of ongoing or planned work. Answering required use of available project data to determine whether issues existed that could impact the start of planned work. Questions were defined based on a set of real project data with input from one of its stakeholders. A proof of concept was implemented to test the value of the proposed solution by creating static 3D models in a BIM tool for a series of panels containing BIM notation placed in predefined BIM views.

Participants included 15 project engineers, superintendents and project managers from two general contractors in the Denver, Colorado area of the US. Participants were assigned to an experiment group or a control group based on availability. Two sessions with each group were held and participants in the control group were asked to answer the questions using the traditional set of inputs consisting of spreadsheets, documents, drawings and non-annotated BIM views.

The experiment group also had access to the proof of concept notations in the BIM views. Questions, as well as the set of project data, were made available to the participants through an experiment website. The questions were embedded in the website as a

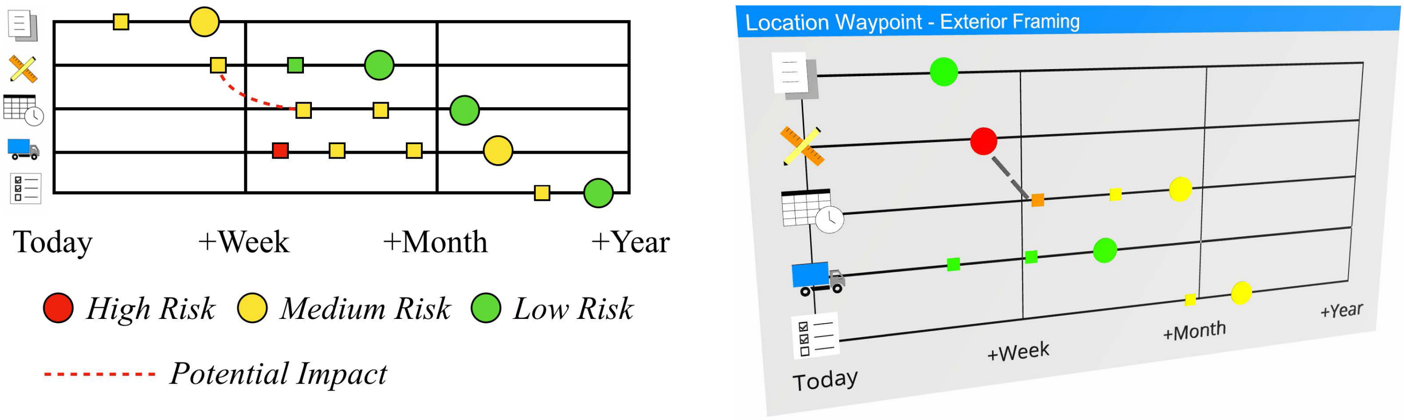

Figure 1: Proposed BIM notation, inspired by music and dance notation (left) and proof of concept implementation in BIM tool (right). The 'staff' is used for five key aspects for successful completion of work: contract documents, design, schedule, material deliveries and QA checklists.

questionnaire and data were automatically collected in a linked spreadsheet. For timing information, the participants were asked to specify the time they started to work on a question. This was used to determine response times, average response time per participant and average response time per group. Responses were reviewed and scored for accuracy and completeness. The hypothesis was that input for decision making by supervisors and engineers could be improved with the introduction of the proposed BIM notations by making targeted, comprehensive data available in a BIM context resulting in less time spent searching for data inputs and more accurate responses.

Results

On average, participants with access to the proposed solution did better: five correct answers compared to three for participants asked the same questions without the BIM notations. The average number of correctly answered questions in control group and experiment group was similar for company 1 and company 2. The results indicate that the presumed ability to answer questions more accurately with the support of the proposed solution could be confirmed within the context of this experiment.

The hypothesis assumed that the time required to respond to questions would be shorter with access to the proposed BIM notation tool. However results showed that the opposite was true indicating a learning curve or usability issues. Senior project managers needed the least amount of time to respond in the control group but the most time in the experiment group. Project and field engineers, participants with less experience, needed more time in the control group and less in the experiment group.

The number of correct answers increased for the experiment group. Proposed BIM notations might therefore address the problem of multiple interpretations of distributed sets of data. Individual interpretation of data sets leads to conflicts between stakeholders due to a preference for their own interpretation or mental model. By bringing all relevant data for an element or a location together, a more comprehensive 'systems engineering view' for construction could be created as a potential lean support tool. If the usability barrier for senior personnel of the proposed solution can be eliminated with suggested improvements, the use of spatially organised information for 'make ready' work may help address current limited adoption of BIM by field personnel. Results indicate that use of BIM technology with the proposed solution most benefitted participants with less industry experience. However, these participants may have had more experience with the use of 3D models for design coordination purposes. The results may also imply that it is difficult for supervisors and engineers without BIM experience to access and consume data through the context of a 3D model. Augmented Reality technology could make interaction with information in a 3D environment easier; a suggestion for subsequent research on this topic.

Empowering next generation decision makers

A significant proportion of experienced construction industry supervisors will retire in the next decade. Results show that experience was a key factor in participants' ability to make decisions based on disconnected data inputs. Experienced supervisors have skills to recognise and utilise important data in large sets, a skill that less senior personnel do not yet possess.

The need for better, more comprehensive inputs to empower the next generation of supervisors and engineers is becoming urgent. Use of data in context through BIM notations appeared to have the most positive impact on least senior participants in the experiment. This points to its potential to enable younger people with less experience to manage jobs.

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The Laing O'Rourke Centre for Construction Engineering and Technology, in the University of Cambridge Department of Engineering, was launched in 2010 with industry partner Laing O'Rourke to fulfil a shared vision of transforming the construction industry through innovation, education and technology. The Construction Engineering Masters (CEM) degree programme is designed to shape the next generation of industry leaders and undertake innovative research projects that deliver value to industry.

Case study

This case study is based upon a paper presented at the IC3E conference (2019), presenting research from a Laing O'Rourke Centre for Construction Engineering and Technology Construction Engineering Master's dissertation titled: *Exploiting Music and Dance Notation to Improve Visualization of Data in BIM* by Marcel Broekmaat, M.Sc. Director of Product Management, Trimble Connect Collaboration Software, Trimble Inc.

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