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Origins and probabilities of MEP and structural design clashes within a federated BIM model

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ABSTRACT

'Design clashes' encountered during the development of a large multi-storey educational building, awarded under a Joint Contracts Tribunal (JCT) Design and Build contract, are reported upon. The building was developed in Birmingham, UK and the contract value was circa £36 million (UK Sterling, 2015). Members of the project management team (PMT) produced designs that were subsequently integrated by the main contractor into a federated building information modelling (BIM) model; at this stage 404 error clashes were evident between the positions of the mechanical, electrical and plumbing (MEP) designer's and structural designer's building compartments. The contractor deemed that these particular clashes were 'mission critical' as previous experience suggested that project costs could spiral uncontrollably if left unabated. Participatory action research was employed to acquire a deeper understanding and knowledge of the clash incidents. Clash data accrued (in mm) was subsequently quantitatively modelled using the probability density function (PDF) and the cumulative distribution function (CDF). Two models produced were the Log Logistic Three Parameter (3P) (using all data including outliers) and Generalized Gamma distribution (excluding outliers). Both models satisfied Anderson-Darling and Kolmogorov-Smirnov goodness of fit tests at α 0.01 and 0.02 levels of significance. Model parameters could be used to forecast similar clashes occurring on future projects and will prove invaluable to PMT members when accurately estimating the time and resource needed to integrate BIM designs. The predictive modelling revealed that 92.98% of clashes reside within the 30–299 mm range while the most probable occurrence of a clash overlap resides in a discrete category of 100–199 mm. Further qualitative investigation is also conducted to understand why these clashes occurred and propagate ideas about how such may be mitigated. The research concludes on two important points, namely: i) BIM is not a panacea to design related construction project rework and that innovative 21st century digital technologies are hampered by 20th century management practices; and ii) improvements in clash and error mitigation reside in a better understanding of tolerances specified to alleviate the erroneous task of resolving unnecessary clashes. Future research is proposed that seeks to: automate the clash detection management, analysis and resolution process; conduct further investigative analysis of the organizational and human resource management influences impacting upon design clash propagation; and devise and validate new procedural methods to mitigate clash occurrence using a real-life project.

1. Introduction

The digital *jacquerie* transcends the narrow confines of the information and communication technology sector and is ubiquitous throughout all industry [1]. This paradigm shift in business and commerce has been enabled through the application of cloud computing [2]. Cloud computing is advantageous to all organizations (large and small) because utilizing internet-based services can reduce start-up costs, lower capital expenditures and increase computational power to augment business/market intelligence [3]. A menagerie of 'networked' digital devices employed within the workplace generates vast quantities of data, information and knowledge that can be further exploited via automated and intelligent analytics [4]. Business intelligence and concomitant data analysis have the inherent potential to uncover patterns, trends and associations related to design data, human behavior, and the interactions between the two, for improved decision making [5,6]. Indeed, the extant literature postulates (cf. [7,8]) that business intelligence enables organizations to gain value from business analytics. Multitudinous benefits of digitization have similarly been promulgated within the architecture, engineering, construction and owner-operated

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(AECO) sector [9]. Prominent digital technologies include: sensors [10]; laser scanners [11]; machine vision [12]; and building information modelling (BIM) [13]. Amalgamated, these technologies have spearheaded the advancement of the digital construction *modus operandi* [71]. BIM is ostensibly the most prevalent of these advanced technologies within extant literature and is gradually becoming conventional in both design and construction practice globally [14]. BIM provides a digital portal through which an integrated project management team (PMT) can collaboratively work upon, and share knowledge of, a construction or infrastructure development pre-, during and post-construction [15,16]. This innovative approach enables PMT members to enhance their inter-disciplinary interactions in order to optimize resultant decisions and afford greater whole life value for the asset [17].

During the design stages of pre-construction, BIM drawings and plans produced by individual designers (e.g. the architect, structural engineer and mechanical, electrical and plumbing (MEP) designer) are integrated into a federated model and tested to identify design clashes [18]. Design clashes consist of 'positioning errors' where building components overlap each other when the original individual designer models are merged. Resolving these design clashes is imperative to project performance, particularly if costly rework is to be circumvented during the construction phase. However, design clash mitigation and the utilization of deterministic modelling to enhance decision making are two areas that have been grossly overlooked within the literature ([19,72]). Given scant research within this important area and the opportunity to improve construction business performance, this work reports upon the findings of participatory action research (PAR) which sought to examine design error clashes that occurred during the compilation of a federated BIM model for a multi-storey educational building development. Such work provides invaluable insight into a previously unexplored area of digital built environment research. The research objectives are to: better understand why clashes occur and engender wider academic debate; demonstrate how the probability density function (PDF) and cumulative distribution function (CDF) can accurately predict the probability of future occurrence for a specific project; formulate innovative ideas for reducing their occurrence and mitigating their impact upon construction business processes and performance; and suggest future work that seeks to maximize business intelligence through automation and apply the deterministic techniques adopted to a larger number of project developments as a means of generalizing the findings.

2. Design errors within digital construction

Design errors are a prominent root cause of diminished construction project performance and manifest themselves as adverse symptoms such as: rework [20–22]; cost overruns [23–25]; schedule delays (*ibid*); and unsafe working environments [73]. Literature proffers that the main sources of design error are inextricably linked to iterative and recurrent design cycles that result from: unanticipated changes [26]; poor management and communication [27]; realignment of traditional/institutionalized organizational and human resource practices [28]; and interoperability between various software platforms [29]. These challenges have engendered frenzied research activity and resulted in the: development of system dynamics models for planning and control [26]; identification of critical design management factors [30]; and examination of causal factors [31]. Despite this herculean effort, anecdotal evidence from industry reveals that design errors remain a persistent problem.

BIM offers a potential digital solution space for design error management as a collaborative and inclusive platform [32]. Yet to date, limited research has investigated whether BIM in the AECO sector is effectively mitigating digital design errors. Love et al. [73] further proffer that the process of design error mitigation implies that:

> "…learning from errors is a collective capacity that can produce individual, organizational, and interorganisational error prevention practices."

Successful error mitigation should therefore nurture learning from within individual design disciplines to encapsulate the entire project team (*ibid*). BIM inherently offers this potential but as the first stage of design error mitigation, clash detection and consequential resolution between design team members has received scant academic attention. Amongst the various structural elements, MEP design errors have traditionally dogged the design process, arguably due to the confined spaces left for MEP systems [74]. Recent research conducted by Peansupap and Ly [33] examined five categories of structural and MEP related design errors, but the study was confined to schedule delays and omitted any discussion on how BIM can facilitate error mitigation at the detailed design stages. Research that has examined design clashes in a BIM environment remains anecdotal or based upon a limited scope of analysis [19,34,35].

2.1. Clash reports and nomenclature

When reporting upon design clashes, the main contractor produces periodic clash detection reports that contain information including: i) thematic groupings of clashes that report upon individual clashes within each compartment category (for example, and in this research 'MEP vs building column' and 'MEP vs building frame'); ii) snapshots of every clash identified to aid communication with all designers throughout the PMT; iii) clash point co-ordinates (as x, y and z co-ordinates) to determine the exact pin-point location of the clash within the federated BIM model; iv) the date that the clash was found; v) clash status (active and unresolved or resolved); vi) a written description of the clash; and vii) a numerical value in metres (m) or millimetres (mm) that specifies the linear magnitude of the positional (clash) error. Manual data cleansing is then undertaken by the contractor's BIM manager using industry nomenclature to define four key clash categories, namely: i) *clash errors* –fault clashes that must be identified and resolved within the federated model; ii) *pseudo clashes* – permissible fault clashes that can be tolerated within the design and do not require resolution; iii) d*eliberate clashes* – intentional clashes, for example, ducting through a floor or web of a structural steel component; iv) *duplicate clashes* – multiple versions of the same 'singular clash' that are repeated throughout a building (e.g. an MEP pipe that travels along the entire length of a structural column will be observed and recorded numerous times even though it actually represents one error). *Duplicate clashes* often originate from one of the three other variants of clash.

3. Research approach

The research design employed participatory action research (PAR) (cf. [36,37]) where the lead researcher was embedded within, and worked closely with, the PMT to develop various aspects of the BIM model. The PMT included the client's representatives (i.e. the building's estates department) and design related disciplines (including the BIM process manager, the lead architect, contractor's construction manager, the contractor's BIM manager, principle designer for mechanical engineering and plumbing and the lead structural engineer). Note that the estate's department held four fundamental roles, namely that of: client's representative; BIM process manager; project manager; and estates department and consequently, covered all three major phases of the building's life cycle. PAR was adopted because it offers pluralistic orientation to knowledge creation and change thus affording greater flexibility to excoriate beneath the corporate façade that can obscure truth in the interests of preserving reputation and consequential profitability. This approach to self-experimentation grounded in experience was augmented by: fact-finding, to acquire a deeper knowledge and understanding [38,39]; learning, through a recurrent process of reflection [40]; and evidential reasoning to interpret information and