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The Implementation of Geotechnical Data Into the BIM Process

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Abstract
Building Information Modelling (BIM) is a relatively new concept to the UK construction industry. With its inception in recent years, the industry is still coming to grips with its utilisation, with around 54% of projects utilising BIM as of 2014. Due to this, BIM has become an extremely relevant topic within the UK infrastructure and the government has instilled an initiative for all centrally-funded projects to utilise BIM as a design tool. However, an optimal BIM strategy has not yet been developed or utilised for transport infrastructure projects which was the primary rationale for this research project. This paper reviews the current BIM process and the limitations it has and how they can be mitigated and, in turn, the process ameliorated in terms of project cost and time. Geotechnical data integration has the potential to improve the BIM process since most projects do not take below-ground data into account. As a result the primary purpose of this study is specifically concerned with investigating how the integration of geotechnical data into the BIM strategy will be possible and how it can influence the process in a cost- and time-saving manner. A number of methods of integrating geotechnical data into the BIM process were considered and critically reviewed, and the potential application of an optimal method focusing on transportation geotechnics was carried out. The research was carried out using a mixed-method approach utilising both positivist and interpretivist strategies. Specifically, a quantitative analysis of a questionnaire survey on qualified UK engineers with industrial experience was analysed together with an analysis of a geotechnical design and construction case study. The results showed that the geotechnical engineers fully support the integration of geotechnical data into the BIM process, while the majority of them consider that this would provide significant cost and time savings in major infrastructure projects as demonstrated in the case study of design and construction of landslip prevention measures for a failed trunk road embankment in Scotland. Utilisation of current data formats through integration with the above-ground data is recommended for a holistic building information model.

Keywords: geotechnical engineering; transportation; building information modelling; earthworks; buried services

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1 Introduction

The UK Government instilled two construction-orientated objectives to be achieved by 2025 (UK Government, 2013): a 33% reduction in initial cost and whole life cost, in comparison to 2009/10 figures and a 50% decrease in the time taken for all new build and refurbished assets from their inception to completion in relation to the industry standards published in 2013 (UK Government, 2013). The adoption of Building Information Modelling (BIM) could be the key to success and help in achieving the aforementioned objectives since it is the process of generating, storing, managing, exchanging and sharing building information in an interoperable and reusable way (Vanlande et al, 2008, Barlish and Sullivan, 2012) and it incorporates all data gathered on a construction project from initiation to decommissioning. The process allows all information collected at each construction stage to be modelled 2D, 3D (Level 1), and 4D (Level 2) and shared in as interoperable data for the lifecycle management of a project (Level 3; Staub-French & Khanzode, 2007). Although the government targets for using implementation of BIM Level 2 by the end of 2016, and plans and standards exist for Level 3 BIM, (e.g. BS8541, PAS 1192), there is still a lack of integration of basic, quality geotechnical data (Level 1) before interpretation and modelling can take place, especially in areas/sites with history of man-made interventions and/or high natural variability. The absence of such data which is difficult to represent in an integrated and interpretable data format (Mokkaram, 2010), as well as its integration into the general BIM process, may seriously hinder the design of the above-ground infrastructure where the BIM process is already well adopted (Race, 2012).

The aim of this study was to investigate the current perception of potential integration of geotechnical data in BIM within the Scottish geotechnical community as well as to explore the needs for geotechnical design data which would help the engineer in designing with BIM (BIM Level 2; target for 2016). To achieve this, we carried out a questionnaire survey within the Scottish geotechnical community and selected a case study of a recent geotechnical infrastructure project to analyse the perceptions and rationale of the involved parties towards adoption and utilization of BIM. In this study, we focus on the geotechnical infrastructure projects where the majority of the infrastructure elements are, or have to be constructed under the soil surface, such as the transportation infrastructure assets, in order to highlight the importance of quality geotechnical data and associated management for future effective asset management.

2 Materials and Methods

Based on the gaps identified in the background and aiming at addressing our research objectives, we framed the project as a comparison of perceptions of geotechnical engineering community with the practical application on a geotechnical project. For this, we used a mixed method of research, involving a questionnaire survey and a case study analysis (Norton, 2009) because it was acknowledged that the response rate to the survey may be too small to represent the whole community. This was followed by a SWOT analysis of the findings of both the survey and case study.

Questionnaire survey: the survey targeted the active members of the Scottish Geotechnical Group (SGG) - a special interest group of the Institution of Civil Engineers and a regional group of the British Geotechnical Association. The objective of the SGG is to promote the Geotechnical Engineering profession, encouraging young people into the discipline and promoting young engineers. The importance of the SGG for this study was that it provides a forum for the exchange of ideas, knowledge and experience concerning the latest developments in the continually developing field of geotechnical engineering. A questionnaire comprising 10 questions was issued to the attendees of a SGG meeting to gauge their perception of the current usage of BIM in geotechnics, The geotechnical data necessary for inclusion in an integrated BIM as well as their views on potential improvements of the BIM process which will involve geotechnical data. The questions were designed to address the aim of the study while trying to avoid the common pitfalls (Norton, 2009) and included close ended questions on the respondents background and current involvement with BIM, as well as open ended questions on the type and importance of geotechnical data and potential enhancements of the BIM process from geotechnical perspective. It was tested it for clarity of instruction and face validity at Glasgow Caledonian University with academic staff and part-time undergraduate students who work in the industry. Descriptive statistics were used to analyse the trends in the responses because of the quantitative nature of the closed questions.

Case study: Descriptive case study method was chosen to illustrate the aspects thought to be representative or typical (Yin, 1984) of the current level of BIM usage on relatively small geotechnical projects in Scotland. For this, we selected a project for stabilization of the embankment of a former trunk road traversing a natural coastal slope detailed in the literature (Mickovski, 2014) where the authors have been involved in. The project site comprises a coastal slope that extends for approximately 850 m and reaches a maximum height of 55 m which is bisected by a former trunk road experiencing subsidence and failures. Lying on the periphery of the Highland Boundary Fault, the geological setting of the site comprises alluvial raised beach deposits of gravel and sands overlying Glacial Till and, locally sands and gravels, of glacial origin. A number of ephemeral springs with a distinguishable seepage line exist on the embankment. Around 60 residential properties lie towards the toe of the slope with the residents using the vegetated road embankment for pedestrian access to the road and the nearby tourist attractions.

The site has a history of slope instability which prompted the local authority who owns the road to investigate the causes of road subsidence and embankment failure as well as to design remedial measures. A range of ground investigations (GI) were carried out and compared to the results of historic ground investigations on the site. The GI included non-intrusive and intrusive techniques described in detail elsewhere (Currie et al. 2010), each of which resulted in a report (factual and interpretative) supported by electronic data files in a large number of formats (AGS (AGS, 2011), DXF, AVI, PDF, ASCII, DOC, XLS).

The design of remedial measures included desk based compilation, summary and interpretation of the above data to derive the ground model, including the characteristic values of the soil strength parameters, which were then used together with the digital terrain model to derive cross sections representative of the locations of the failures. The design included earthworks (excavation, deposition and compaction of re-cycled and imported materials to reinstate the failed sections of the road), structural stabilisation (soil nailing and vegetation to stabilize the embankments), and drainage construction (evacuation of surface and ground water from the road and supporting earthworks; Mickovski, 2014). The design also envisaged longer term monitoring after the construction. The design involved proprietary design software, the information was shared outwith any specific BIM software in a variety of formats reflecting the existing data (ASCII, GSZ, DXF, PDF, DOC), and was delivered on time and at cost as per the Client's requirements, albeit significant time and labour costs were spent on compilation of historical and current data.

Buried structures such as retaining walls, manholes, historic water supply and drainage pipes which were not recorded either in the historical or current GI records were encountered during the excavation. Similarly, evidence of former attempts to mitigate the road subsidence in terms of a number of asphalt layers below the cracked portion of the wearing course and armour rock supports was also encountered but was not recorded previously (Figure 1). These resulted in changes in design and/or construction techniques and, ultimately, labour and time costs.

After the construction period, the 'as-built' drawings were produced in DXF, PDF and DOC format, and the post-construction monitoring continued with the data supplied to the Client in ASCII and XLS format. Due to the limited scope and funding for the project, the output data formats were considered satisfactory for sharing in the future.

Figure 1. Buried structures and services exposed during construction which were not recorded previously: a) retaining structures b) earthworks c) utility pipes below the recorded gas pipe.

3 Results and Discussion

3.1 Results

Questionnaire survey: The survey was issued to 28 core members of the Scottish Geotechnical Group, and the response rate was 75%. The survey revealed that 43% of the respondents consider themselves as geotechnical engineers and approximately 10% consider themselves as mainly working in the transportation geotechnics sector. The survey captured a wide spread of levels of responsibility within the respondents, ranging from graduate engineers (50%) to directors (15%). Similarly, the survey captured the whole range of roles on a geotechnical project, having respondents from engineers working as Clients (4.5%), Engineers/Consultants (68%) and Contractors (27%). The above statistics, which broadly reflect the Scottish Geotechnical Group membership, show that the survey captured relatively broad and representative spread of experience and opinion within the geotechnical community in Scotland.

All respondents agreed that geotechnical data must be included in BIM, and strongly agree that BIM is advantageous to the UK construction industry. More than 80% of the respondents stated that they use BIM, mainly a commercially available package coupled with CAD and proprietary design software. These numbers compare to 54% of BIM users within UK in 2013 (The BIM Task Group, 2013) showing that the target usage of Level 2 BIM on all public contracts by 2016 is a reality, at least in Scotland.

The three main data categories the respondents considered as essential for inclusion in the BIM process are the soil strength parameters (e.g. angle of internal friction, cohesion; 37%), the bearing capacity characteristics of soil (e.g. bearing resistance, CBR; 33%), and the soil stratigraphy (29%). It was interesting that none of the respondents explicitly mentioned buried services or existing underground structures although they often form significant part of the unforeseen ground conditions that hinder project progress (Chandler et al, 2011). Also, it is interesting to note that all data categories identified can be locally very heterogenous and take significant investigation and interpretation to derive characteristic values. However, this line of reasoning tends to be characteristic of structural engineers and similar or typical of a new breed of BIM engineer who would require input data from a specialist discipline expert to input into a model and manage the information in line with the standards and client requirements (PAS 1192-2, 2013).

The key benefits perceived by the respondents are design improvement (25%), clash detection (17%) and collaboration management (13%) but identify that there is little support to model/estimate or do analysis with it (12%). These findings broadly correspond to published literature where the benefits of BIM are cost and time savings (Bryde et al., 2013) which can be achieved by design optimization and collaborative work on shared files, albeit the actual technical capability of current BIM software may not be satisfactory for design and analysis (Lu et al., 2014).

The operational costs associated with BIM hardware and software, have been recognized as the main obstacle in BIM implementation in the past (Lu et al., 2014). However, in our survey, training was identified as a key difficulty at present (56%), followed by cost of implementation (28%) and time consumption (12%). These findings are reflective of the current situation of the industry where smaller companies are struggling to balance compliance costs with the project backlog due to recent increase in spending in the industry.

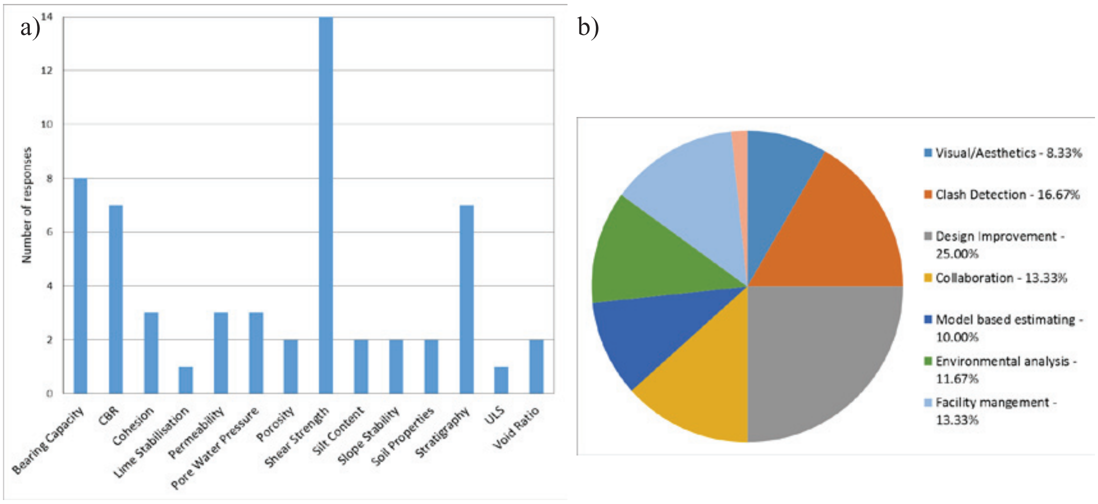

Figure 2. a) geotechnical data considered as essential for inclusion in BIM; b) key perceived benefits of BIM with integrated geotechnical data.

In order to improve the BIM practice, the respondents identified accessibility and flexibility as the key issue (39%) followed by training (23%). These findings are in line with the other findings from the study where the collaborative aspect of BIM shown through a standardized data format and possibility for analysis can provide better accessibility and flexibility. The inclusion of geotechnical data would reflect positively on project costs but the respondents expect time implications, possibly due to perceived data exchange or format (40%). This is reinforced by the finding that almost 2 in 3 of the respondents consider that the gotechnical data should be in the same format as the above-ground data, while 40% of the respondents consider that AGS format is suitable as a universal geotechnical data format that can be shared.

Case study analysis: This project raised several issues regarding the potential use of BIM technology for the geotechnical aspects of transportation engineering and asset management. The main reason for not using BIM on the project was the multitude of formats that geotechnical data came in into the design and the fact that the formats were compartmentalised, not interchangeable, and thus not adequate for the stability analysis or sharing without extensive pre-processing (Barlish and Sullivan, 2012). This was exacerbated with the apparent lack of commercially available software solutions where the geotechnical data can be efficiently analysed, stored, and shared.

Another issue identified was the apparent lack of unified data format that would adequately cover all relevant geotechnical data. The problems with unforeseen ground conditions and historical features did not affect the design or project time, but required changes in the construction methods which resulted in additional costs in terms of construction labour and material (2% of the total project cost). During the excavations for the drainage runs, a number of unrecorded services were encountered which prompted a major change in the design resulting in additional costs in terms of design and construction labour (8% of the total project cost) and project time (10% of the original project duration). This was in line with the key problem that most geotechnical engineers face – the ability to comprehend and extract the significant information and subsequently, manipulating and exchanging said data into other entities (Mokarram, 2010; Chandler et al, 2011). For example, the AGS data (AGS, 2011) can translate well into DXF but is not suited for recording buried structures and features. Similarly, the DXF data can be used as an input into the stability modelling software but the output of such software would be in a format that is not interchangeable.

3.2 Discussion

Both the survey and the case study revealed a number of issues which are summarized in the SWOT analysis shown on Figure 3.

	Helpful	Harmful
Internal (organization)	Strengths: • BIM process familiar to majority of engineers; • familiarity with the current geotechnical data standard; • potential for decrease in time and costs for projects	Weaknesses: • current BIM does not include geotechnical data; • current applications do not incorporate geotechnical design; • small companies may struggle with initial investment in training and software/hardware
External (environment)	Opportunities: • training based on successful application of the process to relevant projects; • development of standard geotechnical data format that includes historical data, buried services and underground structures; • relatively small number of geotechnical data types; • reducing ground investigation risks	Threats: • segmentation and compart-mentalization of the BIM for geotechnical infrastructure projects; • collaborative working and data sharing may be slowed down; • increased project costs; loss of value for money

Figure 3. SWOT analysis of the results from the questionnaire survey and case study on the implementation of geotechnical data in the BIM process.

Building on from the current identified strengths in terms of technical and strategic familiarity with different aspects of the BIM process, the BIM development should include a transition period where target based training is provided especially to smaller organisations who may be struggling to balance investment in training with providing value for money for the clients. This was identified within the case study but also in the survey where the respondents were concerned by the gap between the client requirements and current expertize. The case study project was carried out with very limited budget under a NEC3 contract that incentivised the Contractor to propose savings which will be then transformed into additional work (Mickovski et al., 2013). The case study showed that the project cost savings could have been increased (by reducing the additional costs noted in 3.1) if BIM was used and would have been in the lines of the values reported in the literature (e.g. Bryde et al., 2013; Migilinskas et al., 2013), with the majority of savings during the construction period which would have meant an increase in the cost of planning/design stage of the project. The BIM philosophy would have helped the design if the project management, design and construction teams were well versed in BIM. However, the fact that this project mainly affected the below ground part of a structure and the lack of BIM software that couples the above with the below-ground parts, identified in the survey, made it impossible to justify BIM inclusion in this project. Similarly, the perceived costs of training and potentially lengthy development of a custom-made BIM, also identified in the survey, precluded its inclusion in the project.

The development of standardized geotechnical data format that will take into account relevant and important geotechnical information and interpretation will be of paramount importance for inclusion of geotechnical data in the overall BIM process in a collaborative fashion. Any new development that will incorporate geotechnical data will have to include options for digitizing historical data from the traditional hard-copies with minimum or no manual processing (Morin et al., 2014) to avoid cost and time delays. Even with this option there will be residual risks of unrecorded features or local variation in the properties which should be minimised with each new investigation on a particular site. In the same line, the results of the ground investigations should be documented in an appropriate format and made available, together with any interpretation, to the developers of the above-ground BIM part, giving a detailed insight of the underground conditions. The current AGS format (AGS, 2011) is designed to transfer geotechnical information only and does not cover general site information and in this case, locations of buried services or structures, however this information may be portrayed in the Ground Investigation Report for each project. Commercially available software can make it possible to import subsurface utilities and when viewing the underground utilities it would be possible to view the quality metadata as proposed by PAS 128 (2014) if available. Such software can help in the management of all geotechnical data throughout the lifetime of a project as well as being able to access historical information alongside the current information within the project.

4 Conclusion and Recommendations

The data analysis showed that BIM would benefit from the inclusion of geotechnical data which, in turn, would benefit the project management strategy in terms of cost and time.

Acknowledging the fact that the optimal model of BIM is yet to be found (Bryde et al, 2013), our study identified the integration of relevant geotechnical data in an interchangeable format may improve the design and management process in regards to finance and time factors. However, in the early stages of the development, upfront costs for training and software licensing may be high in respect of the project value and may present a hindrance for smaller companies with relatively little experience in BIM.

The existing AGS format can be adopted as a standard format with adoption of additional changes to take into account historical data or incompatible pre-existing geotechnical data which will have to be pre-processed. Similarly, AGS should be adapted to incorporate data on the subsurface structures and buried utilities in order to achieve the benefits of the BIM process (Morin et al., 2014). However, all of the above will depend on the quality of ground investigation (in the case of the historic structures/utilities) and construction management and monitoring (in the case of newly built infrastructure), and the challenge will be to include the interpretations in an authoritative and interchangeable format, perhaps by using the national geological/geotechnical databases as a basis.

A database of transportation infrastructure projects where the BIM process has been (un)successfully used and where it can be demonstrated that geotechnical data has been incorporated in the process would be of benefit for the geotechnical community as part of the continuous professional development and BIM training which, in turn, will lower the operational costs and improve compliance with the standards.

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