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An approach for semi-automated data quality assurance within BIM models

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A B S T R A C T
Successful Building Information Modelling (BIM) enabled projects that require large volumes of project data to be embedded within BIM models. However, with this wealth of data, relevance and accuracy have been identified as important issues affecting the BIM performance of the project. Currently, Quality Assurance (QA) in the industry has focused on geometric data, including scrutinising physical and spatial clashes. However, as BIM practices progress in the industry, the requirements for non-geometric model data and their quality have become more necessary. This study aimed to ascertain the feasibility of using visual programming for semi-automating the BIM QA process in a practical case study on using BIM in infrastructure projects. This paper outlines a generic semi-automated QA methodology and its application in a construction project case study. The validity of this method was tested and evaluated in practice through (n=2) workshops. The methodology was implemented within an integrated engineering consultancy, employing visual programming methodology to generate QA summaries and additionally highlight model elements with data quality issues based on a defined set of parameters. Based on the evaluation findings, the proposed process was feasible and provided a pathway for low-cost and low-skill QA of BIM model data within the architecture, engineering and construction (AEC) industry. The paper's main scientific contribution is a conceptual framework for using visual programming to achieve automatic quality assurance.

K E Y W O R D S
building information modelling, data quality assurance, model

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Introduction

Globally, the architectural, engineering and construction (AEC) industry continues to embrace a digital workflow, including Building Information Modelling (BIM), which continues to mature and grow in terms of application and adoption (NBS, 2016, 2017). The exponential growth of BIM over the past decade represents a paradigm shift for the AEC industry away from a 2-D drafting-centric approach to 3-D parametric and data-centric modelling (East-

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man, 2011). In the UK, this shift can be partly attributed to governmental support, mandating BIM use in the UK's public sector projects since 2016 (Cabinet Office, 2011), which has been furthered by the BIM recognition as the key driver in attaining the Construction 2025 goals for the AEC industry (HM Government, 2013). This support and endorsement from the government and industry relate not only to the ensued modelling practices but more to the ideal of a wealth of project information existing in a single accessible database and interchanges (Saxon, 2016).

To date, this shift within the AEC industry has resulted in collaborative BIM workflows and processes, utilising the coordination of multi-disciplinary models, and led to measurable benefits relating to time, cost and planning (Ghaffarianhoseini et al., 2015). Therefore, digital data is becoming a key focus for projects and within the industry as a whole. However, as BIM processes and clients mature, the requirements and volume of BIM data associated with models and projects become greater. These data requirements can be considered relative to two main factors. First, they are, in part, due to the current progression in the application of BIM for facility management purposes (Teicholz, 2013). Whereby the as-built digital asset/model is gaining importance, becoming a key deliverable on projects (Carbonari et al., 2018) and also prerequisites for attaining standards, such as ISO 19650 and other globally accepted standards like Construction Operations Building Information Exchange (COBie). Second, with BIM processes becoming a standard practice for many companies, there is a further internal requirement to refine and standardise model data, be it specified by the client or not, to ensure continuity and a high-quality digital output asset, removing an element of risk from the project (Laakso et al., 2016). Subsequently, to further BIM progression within the AEC industry, it is evident that the need for quality-assured BIM model data and the move towards refined standardised models requires additional attention (Howard & Björk, 2008), given no standard procedures currently exist. Currently, there are several approaches offered by commercial software through integrating Business Intelligence (BI) tools to support BIM data analysis. While some of these tools could support Quality Assurance (QA), their use can be costly and so there's a need for other low-cost solutions that can be implemented from standard BIM and open-source tools.

This study, therefore, aimed to ascertain the feasibility of using visual programming for semi-automating the BIM QA process in a practical case study of using BIM in infrastructure projects. The study further proposes a computational logic and conceptual framework for using visual programming for BIM QA focussed on non-geometric data. The study used widely available tools to highlight the requirement for QA of BIM model data within the AEC industry. The methodology was then tested using a case study project within an integrated engineering consultancy. The designed QA process follows a semi-automated computational workflow and is generic in nature, therefore enabling a feasible, low-cost, low-skill and easily adaptable alternative to current manual QA methods. The paper is structured as follows: a literature review outlining the research background is followed by a literature review of the domain. The adopted research methodology is then described, followed by research implementation, which includes the case study adopted for testing. The primary research conducted for validation is then summarised, followed by a discussion and conclusions section.

1. Literature review

Batini and Scannapieco (2016) identified a key principle by distinguishing the difference between information and data. Information is usable and can stand alone as an individual entity, and data has the prerequisite to be ordered with like terms or requires association with a system or object. To this extent, it is clear that given the parametric modelling technique that BIM embodies, associating attributes to individual elements, the information included in models with an incorrect or poor association is of little benefit and non-representative of clear model data or BIM processes. According to a review of current industry practices by Davies et al. (2017), similar problems surrounding the partial or restricted sharing of BIM models can also lead to data clarity issues. Furthermore, Sun et al. (2017) gauged these issues surrounding data and standardisation within the top four most frequently discussed limiting factors hindering successful BIM application across the AEC industry. Subsequently, the topic and importance of correctly defining owners' information requirements are currently gaining attention in the industry and research (Cavka et al., 2017), highlighting a clear need for model data to be useful, manageable and fit-for-purpose, following predefined formats.

Additionally, as concepts of "Big Data" and the "Internet of things" are gaining considerable attention from the AEC and other industries (Scaysbrook, 2016), it is critical that model data-related issues are addressed, enabling interoperability between systems without compromising data loss. Stricter standardisation mechanisms could be put in place to reduce and eliminate model data-related issues, although internally, companies have the immediate ability to reduce this issue by adopting model QA process workflows.

1.1. BIM model information

Two data types are associated with parametric model elements when considering BIM model information in relation to QA. Kensek and Noble (2014) detailed these as geometrical data relating to the geometry and the associated area of elements and non-geometrical based elements with associated attribute information. The value of this incorporation of both data types within a modelling environment has been the long-standing key benefit of BIM (Azhar, 2011). However, as the AEC industry progresses and BIM adoption becomes more widespread, the true potential of the non-geometrical associated attribute information is becoming recognised, particularly for facility management purposes (Lee et al., 2016). Therefore, accounting for this model after use, with the additional consideration that non-geometrical data issues are not prominently visible within the model environment, there is a greater need for quality-assured model data.

1.2. Level of Detail (LOD)

Within BIM modelling practices, the Level of Detail (LOD) represents the section of geometrical data contained within the model. Two clear subdivisions of LOD data should be considered with regard to model QA. First, as detailed by Fai and Rafeiro (2014), they are the geometric graphical representation of elements within the model environment, increasing in detail relative to higher levels. Alternatively, as explored by Donato et al. (2018), they are the sub-set of LOD data, which surrounds the spatial requirements of model elements, relating primarily to maintenance requirements and safe working zones. Consequently, this enables the possibility to quality-assure the model for both hard physical element clashes and soft spatial serviceability clashes.

1.3. Level of information (LOI)

The non-geometrical information contained within BIM elements constitutes the model's level of information (LOI). The correct association of attributes to model elements enable various high-end BIM opportunities to optimise the design and construction process. Most notably, these include operational and energy performance uses (Lee et al., 2016; Peters, 2018). However, data standardisation issues for a model element, outlined by Hjelseth (2010), still form a key barrier to the wider implementation of BIM, even with continued work to refine element data specifications (NBS, 2018). This can be partly attributed to the diverse nature of projects and consequential data parameter needs. However, irrespectively, this places model data QA as a key feature in future BIM practices.

1.4. Level of development

Currently, the relevance of data, as highlighted throughout this background research, is a key BIM model requirement within the AEC industry. Data relevance can be considered dependent upon the desired output. According to Cavka et al. (2017), employers' information requirements need to enhance this process by stipulating desired model data outputs. In considering this relevance of model data, both geometrical LOD and non-geometrical LOI data require specification. Within the AEC industry, this is known by an inclusive term of the level of development (Boton et al., 2015). The level of development, ranging between standardised values of 100–500 with associated requirements (BIM forum, 2017), can relate to the project stage and model progression, but ultimately, it concerns clear client requirements and specifications relative to the perceived model after use. A clear example of the level of development and data relevance can be demonstrated by Motawa et al. (2013), where the key relevance was attached to the desired functionality of the maintenance-orientated BIM model and element attributes relating to the task number and operation outcome. As demonstrated by this example, there would be little benefit in vast amounts of non-maintenance-based information as this would not fit the model's purpose.

1.5. Current industry quality assurance practice and limitations

Having illustrated the need for model data QA within BIM practices, it is important to note that there are software applications currently in use within the AEC industry. Arguably, the most prominent is Navisworks, as a QA application, which is utilised primarily for checking physical clashes between geometric elements in multi-discipline coordinated models (Autodesk, 2018). However, Holzer (2016) introduced a more advanced rule-based tool, the Solibri model checker, which allows potential risks to be reduced by the automated detection of design deficiencies (Solibri, 2018). Additionally, as an Algorithmic rule-based tool, Solibri enables QA options for the associated spatial requirements and tolerances for elements, accounting effectively for the management of all geometrical data.

Model management applications, such as Kinship (Andekan, 2018), represent the final subgroup of model data QA tools. These tools enable the interrogation of model data on a higher level, focusing on model families, file size and designer access rather than model element attributes to locate modelling errors over the project timeline. Furthermore, whilst not primarily focused on QA within the design and delivery phases of a project, a fair amount of QA work and research has been conducted within the AEC industry to compare as-built conditions to BIM model information. However, this relates more closely to geometrical construction accuracy rather than model element data, utilising either point clouds or photogrammetry to highlight and gauge discrepancies between the as-built conditions and the intended BIM model (Kalyan et al., 2016; Han et al., 2015). Other works have relied on ontology to propose the QA process for BIM (Doukari et al., 2022; Doukari & Motamedi, 2022). The previously outlined current tools, whilst beneficial, relate closely to geometrical QA and do not fully accommodate model data quality needs regarding model element parameter attribute information, thus providing validation and the motive for the study presented in this paper. Although studies like Häußler and Borrmann (2020) considered the role of semantic data in BIM QA, the approach towards automation still requires further development. Some tools have become available for integrating BIM with business intelligence (BI) and data visualisation platforms. Whereas these can be applied for some data QA, they remain costly and offer little automation in terms of bidirectional communication with the BIM process.

2. Research methods

Given the background information, there is a demonstrable need for low-cost, automated QA for BIM, particularly for non-geometrical data. This method is envisioned to be used across the design phases, with further application prior to the project handover. Development and trialling of the designed QA process took place at an integrated engineering consultancy within the structural department, utilising a range of complex to simple projects across varying sectors. An example of the BIM Model used for testing the approach is presented in Fig. 1. QA process took place at an integrated engineering consultancy within the structural department, utilising a range of complex to simple projects across varying sectors (Fig. 1).

2.1. Research design

The proposed method sought to develop a semi-automated computational workflow as an alternative to manual methodologies for QA in a BIM process.

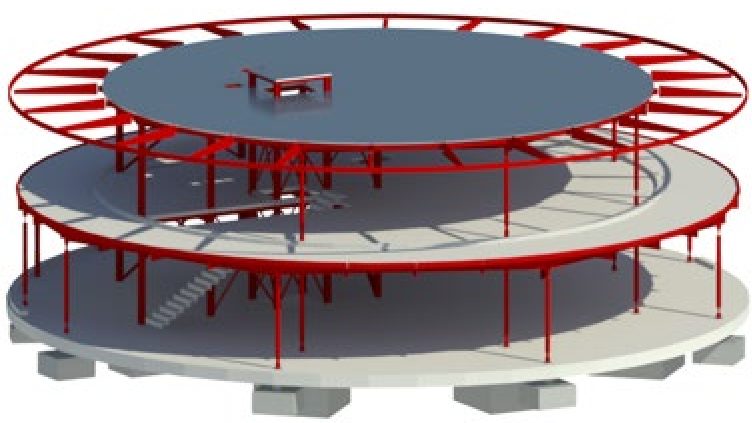

Fig. 1. Low-complexity steel frame community building

The focus on QA in this study was the identification conformance of attached information and parameter attributes associated with structural BIM model elements on a project model during design stages. First, a computational framework was developed and implemented in a visual programming workflow. The method was then tested on a case study of a community building project within an engineering consultancy. The approach and case study results were then validated through two workshops with BIM experts. Similar to focus groups (Creswell, 2013), the workshops allowed the elicitation of industry expert views on the utility and usefulness of the proposed approach while collecting feedback for improvement. Similar approaches have been adopted for testing processes and tools in the BIM domain (Mahamadu et al., 2020). Furthermore, the proposed approach followed up-to-date and current industry progression towards design automation and computational data extraction through rule-based modelling and visual programming (Preidel et al., 2017). The proposed approach was designed to be iterative in nature due to the live dynamic nature of BIM workflows on projects. Therefore, a feasible QA solution must be repeatable, which entails simple process execution reaching a specified format output. A repeatable QA process was achievable, taking inspiration from Preidel et al. (2017), who utilised visual coding to create element constraint queries to check particular variable conditions for validity. The designed QA process in this study incorporates a similar visual coding approach but utilises a workflow, including coded macros within a Microsoft Excel template to format and generate data summaries. The process is outlined in Fig. 2 below.

The tools deployed in the development of the QA process (Fig. 2) were considered due to their availability within standard BIM software (e.g., Dynamo in Autodesk Revit) or wide availability (e.g., Microsoft Excel and Visual Basic). This process eliminates the need for additional programming or plugin complexities in the project workflow (Kensek and Noble, 2014), consequently providing an accessible low-skill and low-cost solution for all users.

2.2. Research implementation

Whilst the designed method included a clear focus hinging upon visual programming to generate the desired output, the implementation of this methodology required specific parameters, workflows and data manipulation techniques, all of which are detailed and examined in the following sub-sections of this study.

2.2.1. Shared parameters

To account for the lack of standardisation and uniformity regarding native parameter attributes within Revit model families, a company/project-specific workflow was followed, allowing parameters to be inserted within all element families. The QA pro-

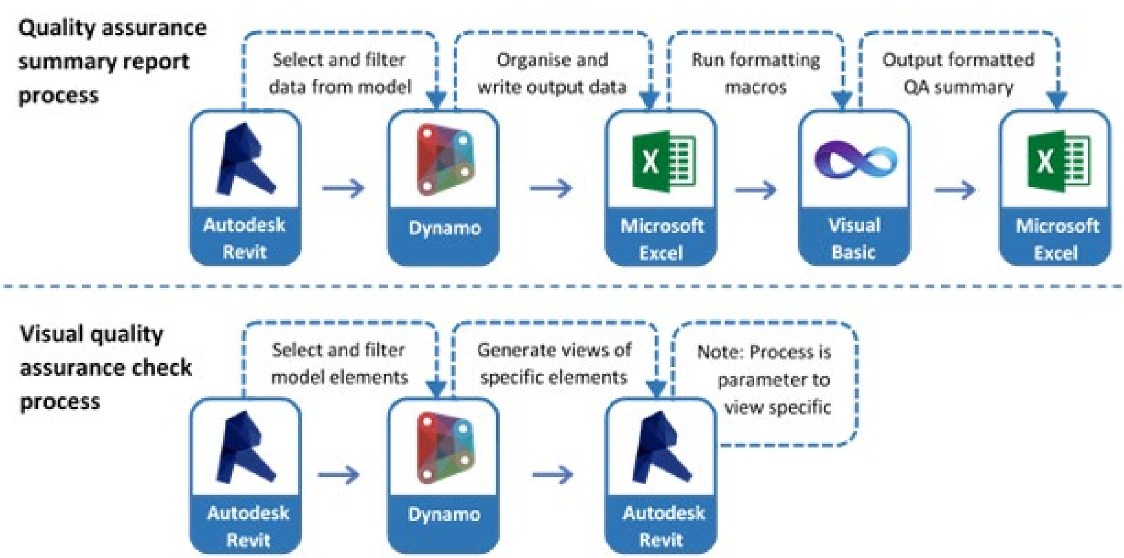

Fig. 2. Process for automated Quality Assurance and reporting for BIM model data

cess then removes ambiguity by ensuring all model elements are adequately included as specified by the company/project requirements (e.g., Employer's Information Requirement). The automation is then implemented for information extraction from the BIM model and then subsequently summarised in a spreadsheet for further analysis. The analysis is used to determine missing parameters and a number of model elements with misaligned information that do not conform to specifications. The total number of occurrences of missing parameters or inadequate information entries can also be ascertained. The five parameters included in this study form the foundation of the QA summary output. The adopted case study was based on structural engineering aspects of a project, thus primarily based on structural elements of the case study BIM model. The included parameters were materials information, LOD, associated model reference levels, element status and material grade (Fig. 3). The methodology thus serves as a filter within the BIM model through visual programming to collate all parameter values for further analysis. The tool can be adapted to accommodate different information or shared parameters.

2.2.2. Process workflow

The presented QA process method was designed with two clear goals, primarily, the summary report on parameter data and the provision of a secondary visual check process in the BIM model. Thus, there is bidirectional communication of extraction, analysis, and summary in the spreadsheet. The summary of the output is presented through visual colour coding of the geometric elements in the model. The primary output was considered to be the generation of a summary report which compares parameter values with what was expected in company requirements on the BIM modelling. This approach ensures that the iterative QA process can occur at predefined intervals following, e.g., the RIBA plan of work stages (RIBA, 2013).

The secondary process of developing visual checks within the modelling environment, as presented, enabled issues to be visually located within the model, enabling faster issue resolution and increased model efficiency. The described workflow process (Figs. 2 and 3) details the linear movement of model data between software applications. Whereby data was extracted, formatted, and output in a Microsoft Excel format to a predefined macro-enabled template. This workflow was used to replace a traditional manual approach to the QA of model parameter data. The approach follows a similar workflow to that presented by Peters (2018), utilising the operability between Dynamo and Microsoft Excel. Lastly, to ensure user accessibility of the QA process, an implementation guide was incorporated into a summary template with the addition of Visual Basic coded formatting macros incorporated as function buttons.

2.2.3. Computational logic

The following equation (1) summarises the approach for computing information quality in the proposed framework. Model Information Quality (MIQ) is expressed as the summation of all elements identified with missing parameter values as a percent-

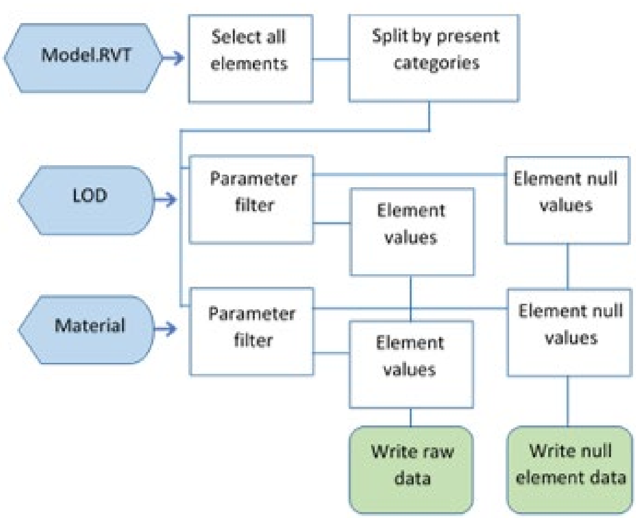

Fig. 3. Process workflow for model-to-Microsoft Excel data extraction

age of elements with required parameter values. In this study, the parameters of interest were: Material Grade, Material Type, Object Status, and Object Level and Level of Detail (LOD). This was assessed in relation to floors, generic model elements, stairs, columns, foundations, structural frames and walls. Equation 1 can be applied to assess information quality for any element or information of interest based on the number of missing key information/parameters detected for each model element.
Where MIQ is the overall model information quality, MI_0 represents instances of missing information or parameters for the relevant model element, and MI_1 represents instances where information exists as specified for the relevant model element.

2.2.4. Semi-automated data quality assurance process in visual programming

$$MIQ = \sum_{i=1}^{n} \left(\frac{MI_{0i}}{MI_{1i}}\right) x\ 100 \qquad (1)$$

Visual programming, which has gained popularity in the AEC industry, enables bespoke activities or functions to be performed within the parametric modelling environment Revit (Kensek, 2014). Furthermore, as suggested by Preidel et al. (2017), visual programming methods are far more intuitive and error-tolerant as opposed to text-based programming languages, allowing ease of adaptability to workflows. In the case of the presented study, the open-source visual programming interface Dynamo, which is now part of standard BIM software (i.e., Autodesk Revit), was used to extract and filter specific parameter data from all model elements, including representation for null values, supplying and writing the raw data to the QA summary template file (Fig. 3). This process required definition from the input of the BIM model by means of the previously examined shared parameters, ensuring the correctly detailed parameter is present in both model and visual programming graph.

Adaptability was further accounted for in the method, in which the Dynamo graphs were constructed, concurrent with best practice policies of companies and the industry, and the use of title captions and colour coding was employed (Fig. 4). Consequently, this increased the level of user confidence regarding possible editing requirements due to the intuitive nature of the method.

Given that the generation of the summary documentation is the primary output of the QA process, the designed visual programming graph consisted solely of "out of the box" or standard nodes, thus eliminating the requirement to download or ensure additional node paths or navigate custom-made coded nodes. The secondary process of creating visual checks within the parametric modelling environment required additional nodes from the Archi-lab package due to limitations within the standard nodes.

2.2.5. Data manipulation

BIM model data was primarily extracted and manipulated within the visual programming environment; however, due to the volume of data, Microsoft Excel provided more powerful and repeatable data manipulation options. The option instilled into the QA process followed a similar data manipulation

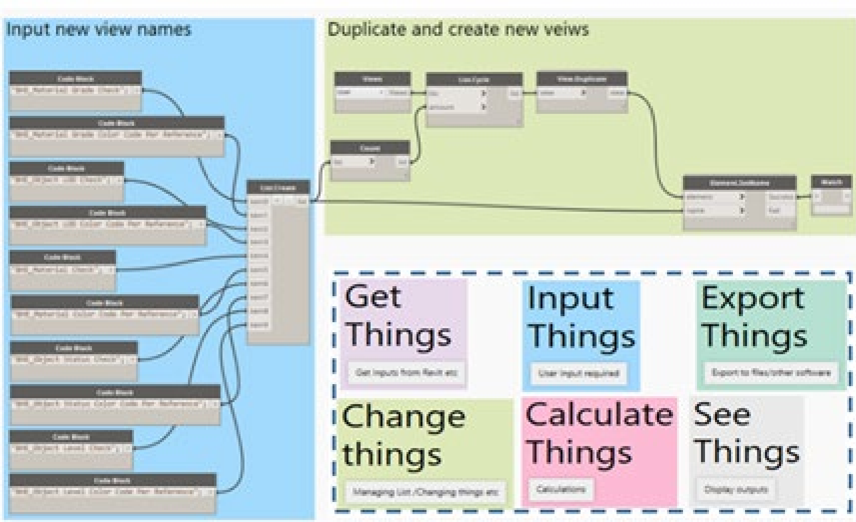

Fig. 4. Example of a Dynamo visual script and colour coding adopted for the organisation of scripts

technique adopted by Khaja et al. (2016) to automate a transfer of data between BIM models and facility management systems through the incorporation of Visual Basic for Applications (VBA) macros. Within the QA process, macros written in the VBA code performed the function of selecting, conditionally formatting and creating summary totals for the multiple parameter data sets, accounting for the variable number of model elements. Assigning the macros to function buttons within the template provided an inbuilt level of guidance and instruction for users, reducing technical ability as a requirement.

3. Research results

The outputs of the model data QA process are detailed in this section of the paper. They relate to the two separate sub-sections of the designed QA process, the primary output of the summary report and the secondary output of the visual check. The presented specific results relate to the steel frame community building (Fig. 1).

The main summary report output is shown in Fig. 5 and was designed to graphically outline the overall number of complete and null value model element parameters in charts in a spreadsheet. Within the summary, the number of completed values is also broken down into a parameter-specific output. As an additional output, the LOD required within BIM documentation is computed and outlined as shown in Table 1. The output shows a count of model element categories with reference to their respective LOD conformance. This summary is then used and returned to the BIM model to provide a visual understanding of QA relative to each element. The output from the secondary visual check QA process (Fig. 6) shows model elements with completed parameter values from the generated view. This process is parameter-specific, with a separate view being created for each of the five previously outlined shared parameters. It is also important to note that in the

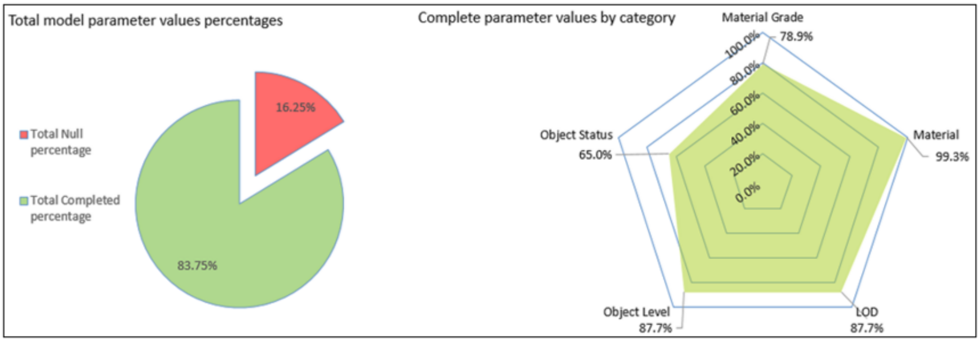

Fig. 5. Overview output of the QA process graphical summary

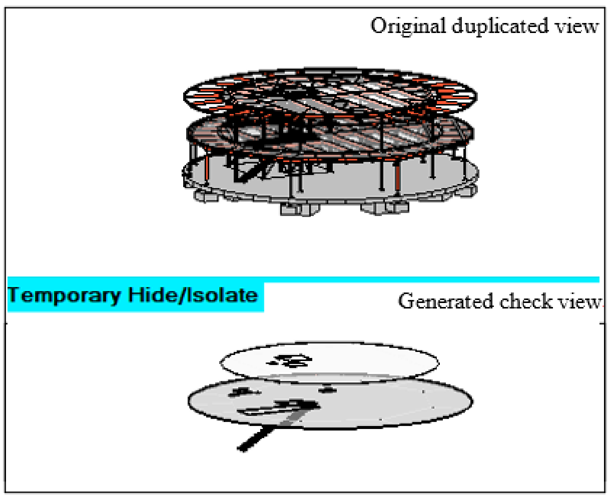

Fig. 6. Visual output of the QA summary in the BIM model

Tab. 1. Model category by LOD classification summary

Model category	LOD Null	LOD 100	LOD 200	LOD 300
Floors	0	13	11	0
Generic Models	3	0	0	0
Stairs	1	0	0	0
Structural Columns	0	0	0	77
Structural Foundations	85	13	39	0
Structural Frame	0	40	0	377
Walls	0	67	0	0

Tab. 2. Workshop participants' views on QA methodology usefulness and relevance

	Theme of validation	Summary of participant sentiments	
		Workshop 1	Workshop 2
1	Relevance to practice	↑	↑
2	Usefulness for the industry's needs	↑	↑
3	Ease of application	↑	↑
4	Ability to enhance continuous improvement	↑	↑
5	Usefulness of results (presentation)	↑	↑

Key: ↑ - Positive; ↔ - Neutral; ↓ - Negative

generation of the QA summary report, project information was automatically read from the BIM model cover sheet and written to title blocks and a relevant project details sheet and the QA summary report.

The proposed method was validated in two workshop sessions with a mix of BIM academics and professionals (n=10 and n=25). The QA process presented functions well and provided clear, useful deliverable outputs generated across a range of steel and concrete framed structural projects of varying scales, primarily educational and commercial projects. Based on the industry's feedback, the QA process is practical, useful, immediately applicable, and relevant. The recommendation suggested applying and testing the approach on a range of other specialised projects, especially complex and larger Mechanical Electrical and Plumbing (MEP) models. Also, further development areas were proposed, including incorporating the baseline benchmarking or recommended values for model data to better quantify and further validate the QA output data.

Workshop feedback was qualitatively analysed with participants representing the academia and external industry BIM professionals. Findings indicated that wider applicability requires tailoring the methodology to incorporate industry-wide data protocols, including UNICLASS and COBie, as part of the computational process to ensure a more generic application to most BIM scenarios. However, the process was deemed "a sound solution for quality assuring BIM model data, improving efficiency and in turn the model delivery process" [the workshop participant's quote]. From the analysis of the responses and feedback, the participants were generally positive about the cost-effectiveness, practicality and user-friendly nature of the proposed QA. The comments were recorded during a thematic analysis to present overall sentiments about the usefulness of the proposed QA method. The three main sentiments were positive, neutral and negative, which were ascertained through thematic analysis as shown in Tab. 2.

4. Discussion of results

Current industry practices regarding the QA of BIM model data are extended primarily to geometric clash-based issues. Additionally, applications surrounding spatially-based constraints are becoming more prominent within industrial processes, installing a further level of QA into projects. However, the literature reveals the need for further research regarding the implementation of QA processes for non-geometrical model element data.

In the case of this paper, the key driver behind designing the model data QA process was design-information efficiency and reliability, partially due to the multi-disciplinary nature of the associated company. However, there are clear alternative benefits to quality assuring model data surrounding facility management and energy modelling options (Lee et al., 2016; Peters, 2018). Furthermore, given standardisation issues related to model element information parameters highlighted by Hjelseth (2010), there is a need to check model information to ensure its relevance to the intended purpose. Given the diverse nature of the AEC industry, the requirements of model data need specification from the employer to ensure fitness for purpose.

The designed QA process sought a generically applicable substitute to current manual-based methods within an integrated engineering consultancy. The method applied throughout the development was one semi-automated computational process reducing the workload and possible errors induced by the reviewer. Given the computational nature of the process and its current, versatile application within the industry, the application of visual programming, Dynamo, was used to extract desirable predefined element parameters. As Preidel et al. (2017) suggested, a primary influence in the application of visual programming for the QA process as opposed to text-based coding was due to its intuitive nature in design and possible future adaptation. The generic QA process, which was designed using only standard BIM tools, accounts for all model categories but would require editing to accommodate additional parameters.

Whilst model data was extracted, initially formatted and exported using the visual programming application Dynamo, post formatting and summary generation used Microsoft Excel. VBA macros were linked to the QA summary template as function buttons. This method was considered given the powerful data manipulation abilities embedded within Microsoft Excel due to the variable scale and the number of model data sets.

As a consideration for further work, the QA process set out in this paper could be easily envisioned and developed into an Application Programming Interface (API) for Revit, removing the requirement to move between Revit and the visual programming application of Dynamo. The detailed QA process consisted of two clear outputs in the form of summary documentation and a visual check generated within views in Revit. Of these, the auditable documentation is of key importance in accessing the data contained within model element parameters. This was achieved by generating completed element parameter percentages on three levels: a model level, a parameter level and a category level. It is important to note that the produced summary results relate solely to data entry within a parameter and does not account for the accuracy of the data. Therefore, if data was provided manually, there is an element of error introduced into the QA summary generation process. The next logical step in the development of the QA summary would entail further work to incorporate model element parameter look-up tables to verify the validity of the extracted model data. Additionally, linking employer information requirements to the LOD data generated within the QA summary would make results clearer. The secondary QA process output of the visual check within the Revit modelling environment provided a quick assessment of areas or categories of model elements with parameter data-related issues. This enabled intuitive parameter editing and correction, installing increased efficiency within the iterative QA process.

Although some methodologies and tools have been developed for BIM QA in practice, there are fewer conceptual propositions on how it can be achieved (Doukari et al., 2022; Doukari & Motamedi, 2022). This study provided a scientific pathway by proposing an equation that can be practicalised using a visual programming approach with the validated and presented conceptual framework. The proposed approach extends previously prosed concepts, including ontology-based methods (Doukari & Motamedi, 2022), towards a more practice-oriented approach.

Conclusions

The research described in this paper proposes a viable solution to QA of BIM model data within an integrated engineering consultancy with a presentation of novel expression as well as an approach to visual programming that can be universally adopted using BIM software. Given the methodology followed, using only standard BIM tools, the presented process is a feasible and cost-effective option for widespread development within the AEC industry. The implementation of a QA process for model data, as outlined in this paper, would not only improve the modelling efficiency but also more effectively accommodate future facility management and energy modelling requirements. A methodology has been presented as well as a framework for using visual programming to achieve the developed mathematical expressions. One of the key advantages is the generic nature of the proposed framework, which allows for modification depending on information requirements for each practice or project scenario.

This research was conducted in conjunction with an integrated engineering consultancy as a result of operational desires to further incorporate computational BIM into work processes and background research. The background research highlighted a lack of standardisation within BIM model element parameter data and a growing requirement for this data to be quality assured as the AEC industry and BIM practices progress in meeting future needs. Therefore, while designers must have the ability and knowledge to deliver BIM models to a high standard, moving forward to future practices and subsequent applications within the industry, the level of data assurance will become a key aspect of project delivery.

The key contributions are as follows:

- There is a growing requirement for BIM data QA within the AEC industry.
- There remains a gap in standards for information quality definition as well as benchmarking.
- Moving forward towards future BIM practices, a greater level of standardisation needs to be agreed upon for information definition as well as benchmarks of quality relative to prescribed levels of information. A novel computational logic and conceptual framework have been proposed based on the development and testing of visual programming approach for BIM QA.
- The application of a semi-automated QA process is a feasible option using standard BIM tools.
- Visual programming represents a key area of advancement for the AEC industry, allowing clear data manipulation abilities.

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