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EXPLORING THE USE OF PARAMETRIC DESIGN IN THE AEC SECTOR TO IMPROVE AND ENSURE QUALITY OF DRAWINGS

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SUMMARY*: As the Architecture, Engineering, and Construction (AEC) sector progressively embraces digital technologies, there is an emergent necessity to explore the capabilities of these tools in enhancing quality assurance and review processes during the design phase. Therefore, this study seeks to answer the following two research questions: RQ1: What types of errors can be effectively addressed using a parametric tool? RQ2: How can parametric tools be employed to ensure quality in architectural drawing and what are the potential benefits and limitations of this approach? The research employs the Design Science Research Methodology, which includes identifying issues related to drawing reviews through interviews with five industry professionals and the development of a parametric design script for drawing checking. The findings of this research have led to the development of two scripts that serve as model artifacts at a proof-of-concept level demonstrating the possibility to employ parametric design for drawing reviews. Further research could be conducted to investigate other possible applications of parametric design and automatized procedures in the AEC sector.*

KEYWORDS*: Quality assurance, Dynamo, Compliance checking, AEC, BIM, Visual programming language.*

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1. INTRODUCTION

As digitalization progresses, the Architecture, Engineering, and Construction (AEC) industry is compelled to adopt and implement new technologies. Over the last decade, Building Information Modeling (BIM) has been widely adopted in the construction sector. BIM technology enables the creation of digital models of projects, showcasing functional characteristics that facilitate decision-making throughout a facility's lifecycle, thanks to information-rich models (Wang et al., 2019).

Construction projects are often complex, each with unique assumptions. The success of these projects relies heavily on the delivery of high-quality design outputs (Koo and O'Connor, 2022). The International Organization for Standardization (ISO) defined quality in 2005 as the "degree to which a set of inherent characteristics fulfills requirements," such as client specifications and national guidelines. For instance, 'Bygghandlingar 90' by Bergenudd (2003) provides specific recommendations for interpreting symbols and terms within the Swedish AEC sector. Additionally, Kovacs and Micsik (2021) introduced four types of BIM compliance checks based on state-of-the-art theories and solutions from prior studies. Their research also involved market research to evaluate tools available for compliance checks, delineating four types of checks: validation, model content, smart objects, and design options. The use of BIM and other digital tools has significantly increased in the AEC industry, as these tools have been proven to enhance project outcomes (Koo and O'Connor, 2022). These authors identified 160 leading indicators for design defects, with 114 potentially supported by BIM. This burgeoning interest in BIM has spurred a shift towards a digitally oriented culture, focusing on 3D models rather than traditional 2D drawings. However, Dosumu (2018) noted that one of the most common causes of reduced performance in construction projects is errors in contract documents, with drawings accounting for over 60% of these errors. Documents produced for construction projects must be of high quality. Govender et al. (2022) observed that poor-quality tender documents often contain inaccurate, unclear, or omitted information, asserting that high-quality tender documents are vital as they can mitigate the risk of increased costs and delays. The researchers identified six quality indicators for tender documents: accuracy, clarity, completeness, relevance, standardization, and certainty, which are also applicable for assessing other project documents, such as drawings. Kim and Chin (2019) highlighted that errors often occur when 2D documents are derived from BIM models, typically requiring additional efforts to finalize these documents. Xue and Zhang (2022) emphasized that traditional design review processes heavily rely on manual efforts, posing a high risk of human errors. Improving the quality of building construction necessitates designs that comply with various standards, including owner requirements and building codes (Koo and O'Connor, 2022). However, the manual process of aligning design documents with rules and regulations often leads to errors and omissions (Lee et al., 2019). Dosumu (2018) categorized several types of errors in contract documents, including design, dimensional, and symbol errors, omissions, and violations of building codes. Despite the increased use of 3D models, 2D drawings and documents remain crucial in construction projects. As Dosumu (2018) pointed out, design documents frequently lead to reduced project performance, resulting in increased costs and delays. Manual document review processes are laborious and prone to errors (Lee et al., 2019). Parametric design, known for its speed and accuracy (Lin et al., 2022), could potentially streamline the sluggish and error-prone document review process.

With the growing utilization of BIM, other digital tools like parametric design are being explored to digitize the AEC industry further. The mechanical industry has seen notable advancements with parametric design, facilitating knowledge and experience exchange. This positions parametric design as a promising avenue for design tools (Lin et al., 2022). Parametric design offers speed, stability, and accuracy. Lin et al. (2022) researched a parametric design platform designed to generate 2D drawings and 3D models in compliance with ISO 13399 standards, which standardize the expression of cutting tool information to facilitate data exchange in design, manufacturing, distribution, and use (International Organization of Standards, 2006). The research also includes a comparison between traditional modeling and parametric modeling for producing 3D models and 2D drawings. The authors concluded that parametric design can increase efficiency by up to 90% in the mechanical industry. In the construction industry, the use of parametric design has become more prevalent, particularly in the early design stages for exploring various design options (Brown and Mueller, 2018). Brown and Mueller (2018) presented a workflow using parametric design for performance-based design along with simulations, primarily to analyze design variables in the early design phases.

The potential application of parametric design in other areas needs further exploration. Additionally, Lou et al. (2022) observed that the adoption of digital technologies for Construction Quality Management (CQM) represents a nascent field. Notably, the application of parametric design to enhance the quality of tender documents remains largely unexplored.

The primary aim of this study is to assess the viability of using parametric design as a tool for quality assurance in the creation of architectural drawings during the design phase, and to develop a corresponding prototype. The research is structured around the following key questions:

1. What types of errors can be effectively addressed using a parametric tool?
2. How can parametric tools be employed to ensure quality in architectural drawings and what are the potential benefits and limitations of this approach?

This inquiry seeks to extend the current understanding of parametric design applications beyond traditional uses, exploring its potential to improve document accuracy and reliability in construction projects significantly.

2. METHODS

To demonstrate the practical potential of utilizing parametric design as a quality assurance tool, parametric design scripts were developed at a proof-of-concept level. This approach aimed to showcase the applicability of the technology and explore its feasibility. For this study, a comprehensive scoping review and document analysis were conducted. Additionally, a case study was carried out at a leading Swedish consultancy firm, focusing on a train station project, which included both its 3D model and architectural drawings. This case study provided a real-world context to examine the effectiveness of parametric tools in ensuring drawing quality.

The research methodology drew upon the framework established by Peffer et al. (2014), who outlined the Design Science Research Methodology (DSRM) for information systems. This methodology includes six pivotal stages: problem identification and motivation, defining solution objectives, design and development, demonstration, evaluation, and communication. While the iterative nature of the DSRM was not fully implemented due to study constraints, the output of the design science effort, following the DSRM, results in artifacts which can be classified into four categories: constructs, models, methods, and instantiations (Hevner et al., 2004). In this context, the visual programming scripts developed in Dynamo are considered model artifacts designed to tackle the identified issues.

To address the first research question (RQ1), a document analysis and scoping review were conducted to explore current technologies, standards, and the state-of-the-art in construction quality assurance. For the literature review, databases such as Primo, Web of Science, and Scopus were utilized, with search terms including "AEC," "construction," "architecture," along with "drawing," "error," "parametric design," "design phase," "issue," "standard," and "quality."

Semi-structured interviews were conducted to gain deeper insights into existing workflows for drawing quality checks, prevalent errors, and the parameters associated with these errors. Based on the insights gathered, it was hypothesized that the second research question (RQ2) could be effectively addressed through the development of parametric design scripts. These scripts were designed to facilitate and enhance the quality assurance of drawings.

The script development process adhered to the workflow outlined by Di Guida et al. (2021) for rule-based compliance checking. Additionally, the four principles for developing automatic compliance checking tools, as outlined by both Kovacs and Micsik (2021) and Di Guida et al. (2021), were incorporated. Instead of directly translating building codes into semi-formal rules, the parameters identified through interviews and the literature review were transformed into script parameters. Furthermore, Kovacs and Micsik (2021) defined four types of compliance checking, among which "Model Content Checking" was reinterpreted as "Drawing Content Checking" in this study, emphasizing an assessment of the informational quality of drawings. Figure 1 in the study illustrates the interconnections between these methodologies and workflows, demonstrating the integration and application of these principles in the context of parametric design.

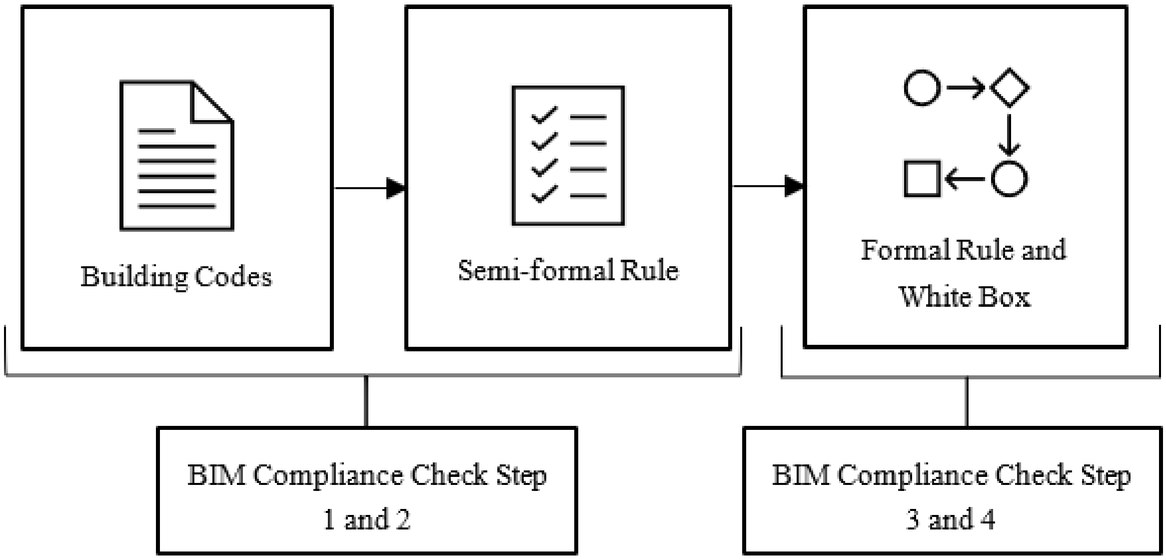

Figure 1: Adapted from Di Guida et al. (2021) combined with Kovacs and Misik (2021) steps for BIM Compliance Checking.

2.1 Interview process

Following the completion of the scoping review, a series of interviews were conducted to gather accurate and relevant information. These interviews involved professionals who are pertinent to the study, ensuring a comprehensive understanding of the practical aspects of parametric design in quality assurance processes. A total of five individuals were interviewed, including two architects, two data coordinators, and one structural engineer. The table below details their respective work experience and current roles. To preserve the confidentiality and anonymity of the interviewees, each participant is identified by an individual code, as outlined in the table. This approach maintains the integrity of the data while respecting the privacy of the participants.

Table 1: Interview participant information.

Code	Current Role	Using parametric tools daily	Experience
A1	Architect	No	13 years
A2	Architect	Yes	7 years
D1	Data Coordinator	No	8 years
D2	Data Coordinator	No	4 years
S1	Structural Engineer	Yes	7 years

All individuals interviewed for this research are current employees at the company where the case study was conducted. Selecting interview participants from the same company was a strategic choice aimed at gaining deeper insights into their internal workflows and collaborative processes. Each interviewee brings specialized expertise in their respective fields, offering valuable perspectives and experiences that enrich the understanding of the study. Semi-structured interviews were utilized for data collection, a method recommended by Säfsten and Gustavsson (2019) for its ability to elicit detailed and highly valid information. An interview guide was carefully prepared following the guidelines provided by Säfsten and Gustavsson, ensuring a structured yet flexible approach to the interviews. This method aligns with the recommendations outlined by Bryman and Bell (2015), emphasizing the importance of methodological rigor in qualitative research. The interview guide included six primary questions with an additional four supplementary questions designed to probe deeper into specific areas. Five of these questions focused on the current workflows specific to each discipline, experiences with parametric design, and their processes for reviewing architectural drawings. The final question was based on the minimum required elements within drawings as identified by Kim et al. (2022), aiming to correlate these elements with common errors observed during the drawing review process. The interviews were conducted online via Microsoft Teams, facilitated by one author posing questions while the other took detailed notes. Each interview was recorded with the consent of the interviewees to ensure accuracy and thoroughness in data collection. Following the interviews, the data were summarized and shared with each participant for validation, adhering to ethical research practices as suggested by Bryman and Bell (2015). This process not only confirmed the integrity of the information gathered but also provided an opportunity for interviewees to clarify or expand upon their responses, thereby enhancing the overall quality and reliability of the research findings.

2.2 Evaluation process

Hevner et al. (2004) delineate a variety of evaluation methods suitable for assessing the effectiveness of technological innovations. In this study, testing and experimental methods were specifically chosen based on two principal criteria: functionality and usability. Functionality, as defined by Padayachee et al. (2010), refers to the software's capability to provide functions that meet both explicit and implicit user needs under certain conditions of use. Usability, on the other hand, relates to the ease with which the software can be understood, learned, and used, alongside providing an aesthetically pleasing interface, all within specified usage contexts. For the evaluation of the developed parametric design scripts, three BIM coordinators (B1, B2, and B3) from the consultancy company were involved. It is important to note that these BIM coordinators were not part of the initial interview group discussed earlier, thereby providing a fresh perspective on the assessment of the scripts. Prior to the evaluation, the participants were thoroughly briefed about the scripts' functions and potential uses. They were also provided with a user manual that served as a detailed guide, along with a sample case to practically apply the scripts. A computer equipped with the necessary software and data was prepared for each coordinator to facilitate the testing of the scripts. Following the hands-on session, each participant took part in a structured interview designed to gather their insights on both the functionality and usability of the scripts. The interview questions, adapted from Kebede et al. (2022), aimed to capture comprehensive feedback on the user experience and the effectiveness of the scripts in real-world scenarios. The outcomes of these interviews were then summarized and presented back to the participants for validation, ensuring accuracy and participant agreement with the recorded responses. Based on the feedback received during these interviews, the scripts were further refined to enhance their performance and user interface. Table 2 below summarizes the key questions posed during the interviews, reflecting the structured approach taken to evaluate the scripts and implement necessary improvements based on real user experiences. This process not only validated the functionality and usability of the scripts but also contributed to their continuous development, ensuring their alignment with user needs and industry standards.

Table 2: Evaluation interview questions, adapted from Kebede et al. (2022).

Characteristic	Sub-Characteristic	Question
Functionality	Suitability	Can the method perform the expected task?
	Accurateness	Does the method achieve the desired outcome as intended?
	Compliance	Does the method meet existing industry requirements?
Usability	Understandability	Does the user comprehend how to use the method easily?
		Was it easy to install the script and the necessary components?
	Learnability	Does the method operate with minimal effort?
		Is the method easy to learn?
	Operability	Does the method make it easier to complete tasks quickly?
		Does the method improve the existing workflow?

3. RESULTS

This chapter outlines the results of the study, detailing the sequential findings that build upon each aspect of the research process.

3.1 Scoping Review Results

The study commenced with a scoping review aimed at identifying the current standards, technologies, and best practices in quality assurance within the AEC industry. This review helped establish a foundational understanding of the domain, setting the stage for the subsequent phases of the research. The findings from this review are critical as they informed the development of the interview questions and the design of the parametric design scripts.

Agbaxode et al. (2021) have highlighted that globally, the quality of design documentation frequently falls below standards, characterized by unclear, inconsistent, and insufficient information. This deficiency leads to project delays, compromised project quality, and escalated costs. Agbaxode (2021) further emphasizes the critical importance of accuracy and clarity in design documents due to their significant impact on project execution.

The adoption of digital solutions like Building Information Modeling (BIM) holds promise for enhancing overall document quality. However, despite the construction industry's shift towards digitalization with 3D models, the need for 2D drawings persists, primarily due to their continued legal significance in construction projects, as underscored by Kim et al. (2022).

Kim and Chin (2019) have identified three primary challenges associated with extracting drawings from BIM: the inevitable additional work required, limitations in drawing representation based on the level of detail, and slow processing speeds. They noted that typically, an additional 25% of work is required to complete the drawings after their extraction from BIM software.

In their analysis of 2D deliverables in construction documentation, Kim et al. (2022) pointed out several essential elements that must be included in drawings, such as scale bars, design change indicators, and dimension elements.

Villaschi et al. (2022) argued that integrating parametric design tools like Dynamo with BIM models in Autodesk Revit facilitates the automation and analysis of urban compliance indices. They contend that parametric design tools can significantly enhance the speed and reliability of results, leading to higher-quality analyses. These authors suggest that such software could become an integral part of the automation process for compliance assessment.

Di Guida et al. (2021) developed a method to integrate building code checking into BIM software using Dynamo, establishing a structured approach for creating compliance checking rules and outlining an implementation process. Their research adheres to principles of replicability, including coherence, uniformity, and automation, facilitating easy adaptation for similar needs, such as compliance checking for drawings. They also discussed two distinct software development approaches: the white-box approach, which, despite requiring more effort and expertise, provides greater transparency by making internal processes visible; and the black-box approach, which conceals processes except for input and output data and requires software vendor involvement for modifications, offering the advantage of relatively lower error rates.

Both Villaschi et al. (2022) and Di Guida et al. (2021) concluded that Dynamo is capable of assessing and processing all characteristics of a BIM model, enabling both qualitative and quantitative assessments.

In summary, the scoping review underscores the importance of maintaining high-quality project documentation, especially for 2D documentation which often carries legal implications (Kim et al., 2022). Furthermore, the subpar quality of design documents, as indicated by Agbaxode et al. (2021), leads to significant project challenges, including delays and increased costs. Despite the potential for quality improvements offered by BIM, the necessity for additional work on 2D drawings extracted from BIM software persists. Moreover, parametric design tools are anticipated to play a critical role in compliance assessment due to their efficacy and reliability in generating results, thereby enabling a comprehensive assessment of all aspects of a BIM model, both qualitative and quantitative.

The insights from the scoping review have been instrumental in informing the development of parametric design scripts for compliance checking, ensuring alignment with industry standards and national guidelines related to quality assurance, such as Bygghandlingar 90 (Bergenudd, 2003).

3.2 Interviews results

Following the scoping review, interviews were conducted with various professionals at the consultancy company. These interviews were instrumental in gaining insights into the existing workflows, common errors in drawing reviews, and specific needs that could be addressed by parametric design tools. The results from these interviews provided a practical perspective on the challenges and requirements of quality assurance in architectural drawings, which directly influenced the script development phase.

In contrast to the automated tools discussed earlier, D1 and D2 employed a more traditional approach to the review of drawings before client delivery, typically conducting three reviews per project. The process commenced with an internal review to ensure alignment with client requirements, followed by the submission of documents to the client. Before delivery to the client, a cross-disciplinary meeting was convened where representatives from all involved disciplines compared and reviewed their respective models.

During the document review process, D1 and D2 relied on a checklist, which was used primarily in a manual context. Additionally, they utilized Autodesk Vault—a database designed to manage project-specific metadata. This metadata was meticulously cross-referenced with the information contained in the reviewed documents to ensure consistency and accuracy. Any errors discovered during this review process were compiled and forwarded to the respective disciplines for correction. Furthermore, a record of these issues was maintained in a list, which was published on their internal communication platform and regularly updated as each discipline addressed the identified errors.

Despite the variations in review processes among the departments, a common theme highlighted by all participants was the manual nature of these processes. D2 specifically pointed out the absence of software tools for reviewing the content within the drawings, such as stamps and symbols, underscoring a significant reliance on traditional, hands-on methods. This reliance on manual processes, while thorough, suggests potential areas for enhancing efficiency and accuracy through the integration of automated tools and software solutions.

> *"I verify that the stamp on the drawings coheres with delivery specifications. I also verify that drawings contain connections, coordinate crosses, scale bars, orientation figures, and directional indicators. I am not using any software to perform these checks, I do it manually."* – Participant D2

Moreover, D1 expressed that a higher level of automation during the review process would be beneficial.

> *"After all, we have parameters to which we must adhere, i.e., the client requirements. But we don't use scripts to the extent that we could do."* – Participant D1

A2, D1, and D2 emphasized that errors in architectural drawings often originate from human factors, including carelessness, data entry mistakes, and lapses in critical information sharing among project participants. These insights underscore the vulnerability of manual processes to human error, highlighting the potential for oversight in crucial project stages.

Moreover, A1, A2, and S1 noted that issues might also arise from participants lacking sufficient technical knowledge, which can lead to the incorrect use of modeling software. This factor can significantly impact the quality and accuracy of the drawings produced, emphasizing the need for adequate training and expertise in handling specialized software tools.

All interview participants agreed that the manual nature of the drawing review process contributes significantly to the incidence of errors going undetected. This consensus points to the inherent limitations of traditional review methods, where the reliance on manual checks increases the likelihood of overlooking errors, thus affecting the overall project outcomes.

To further explore these issues, the final question in the interview guide was based on parameters identified by Kim et al. (2022) as critical to the quality of architectural drawings. The table below provides a summary of the interview results, illustrating which parameters are most commonly associated with typical errors in the drawing review process. Each parameter listed in the table is accompanied by the number of interviewees who reported encountering errors related to these specific aspects during their reviews. This data offers valuable insights into the most prevalent issues within drawing reviews, guiding future improvements in the review process and the potential integration of automated tools to enhance accuracy and efficiency.

Table 3: Number of interviewees that have identified common errors connected to required parameters.

Required parameters in architectural drawings	Number of interviewees identifying errors related to required parameters
Drawing information (e.g. name, number, date, version)	3 out of 5
Symbols (e.g. scale bar, north arrows, direction of stairs)	5 out of 5
Name/Label (e.g. room name, floor name, grid lines)	4 out of 5
Line types	3 out of 5
Shadows (e.g. material/pattern, cross-section)	3 out of 5
Dimensions (e.g. dimensional elements, areas, heights)	3 out of 5
Regulations/technical descriptions (e.g. information in the stamp)	4 out of 5
Others:	
- SWE REF coordinates differential between disciplines (e.g. architects and landscape architects)	1 out of 5

Drawing from the interview results, it becomes clear that errors most frequently occur within the 'Symbols' parameter group. This insight was particularly underscored by D2, who noted that a significant portion of their manual review process involves careful examination of north arrows, a common yet critical element in architectural drawings.

Given these findings, the development of the parametric design scripts has been specifically tailored to address these prevalent issues. The scripts have been enhanced to focus on the analysis of symbology, with particular emphasis on north arrows. This targeted approach allows for a more thorough and automated verification of symbols used in drawings, aiming to reduce the incidence of errors related to incorrect or unclear symbology.

This focus not only aligns with the identified needs from the interviews but also leverages the capabilities of parametric tools to provide a systematic and precise analysis, thereby improving the overall quality and accuracy of the drawing review process. The implementation of these scripts represents a proactive step towards mitigating the manual challenges highlighted by the professionals, potentially transforming how quality assurance is conducted in architectural documentation.

3.3 Dynamo script

The final phase of the study involved the evaluation of the developed scripts by three BIM coordinators. This evaluation was crucial to validate the functionality and usability of the scripts in real-world settings. The feedback received was thoroughly analyzed and used to refine the scripts further. This section presents the results of the script evaluations, discussing both the strengths and areas for improvement as indicated by the BIM coordinators' experiences and responses.

Drawing from both the interview results and the scoping review, two scripts were meticulously developed to enhance the quality assurance processes in architectural drawings, specifically targeting the accurate representation and orientation of north arrows.

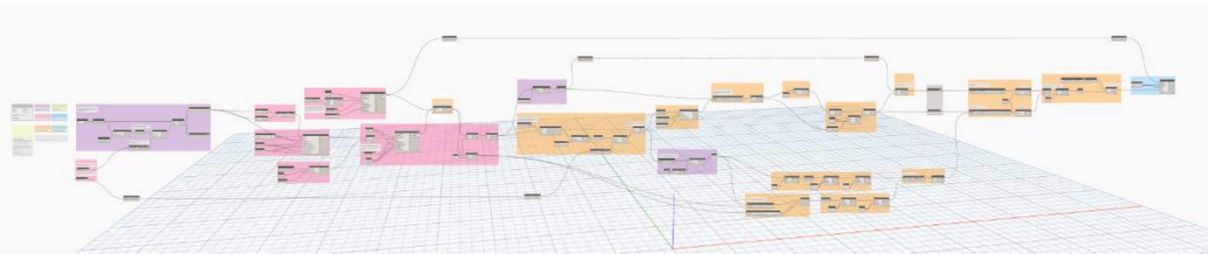

Figure 2: Dynamo script overview.

Script 1: Reporting of Errors

This script is designed to scrutinize architectural drawings for the presence and correct orientation of north arrows, exporting the pertinent data to an Excel file for further review and documentation.

Step 1: Filter Architectural Plan Drawings

The script begins by selectively filtering architectural plan drawings within the project, adhering to the naming regulations specified by the Swedish Standards Institute (SIS, 2016), typically denoted as "A-40.1" followed by floor level and a serial number if applicable.

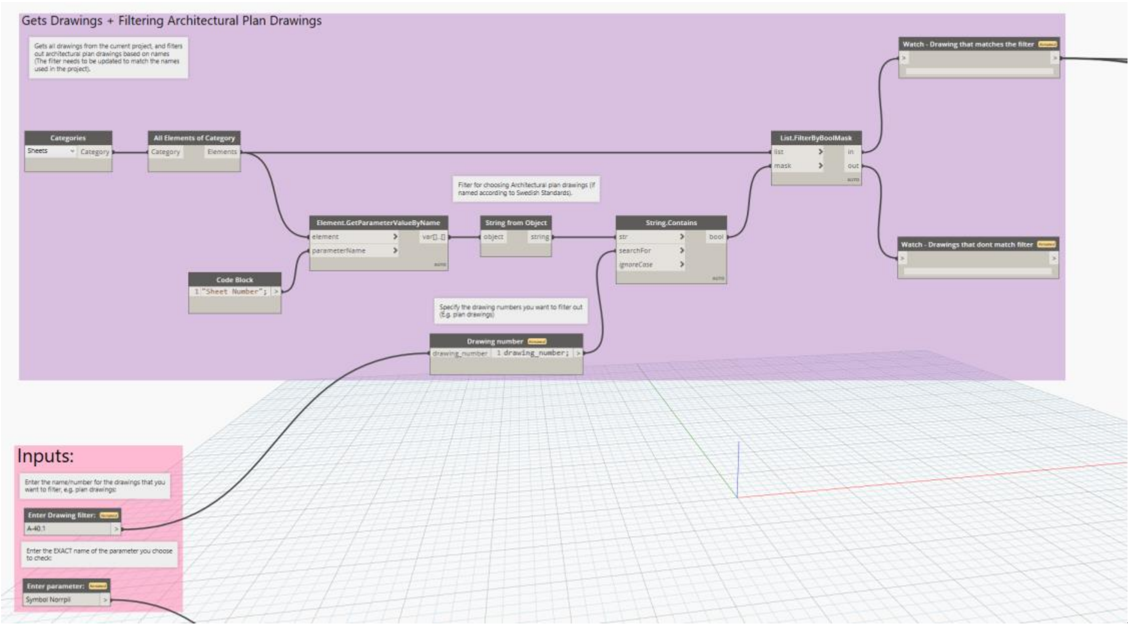

Figure 3: Step 1: Filter Architectural Plan Drawings.

Step 2: Select Drawings and Project North (UI)

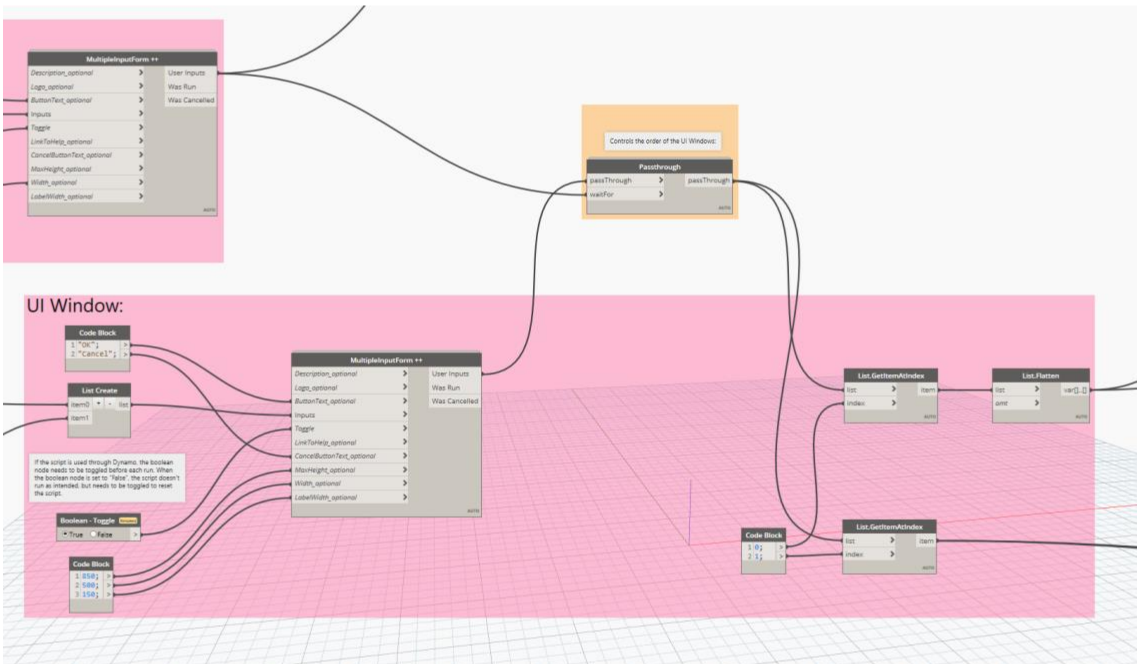

Figure 4: Step 2: Select Drawings and Project North (UI).

Executed through the Dynamo Player in Autodesk Revit, this step allows users to select specific drawings for inspection and to set the project's north angle. Users also define the file path for the Excel document for data exportation.

Step 3: Searching for North Arrows

The script assesses the selected drawings to identify the 'Generic Annotations' category within Revit, where north arrows are typically categorized.

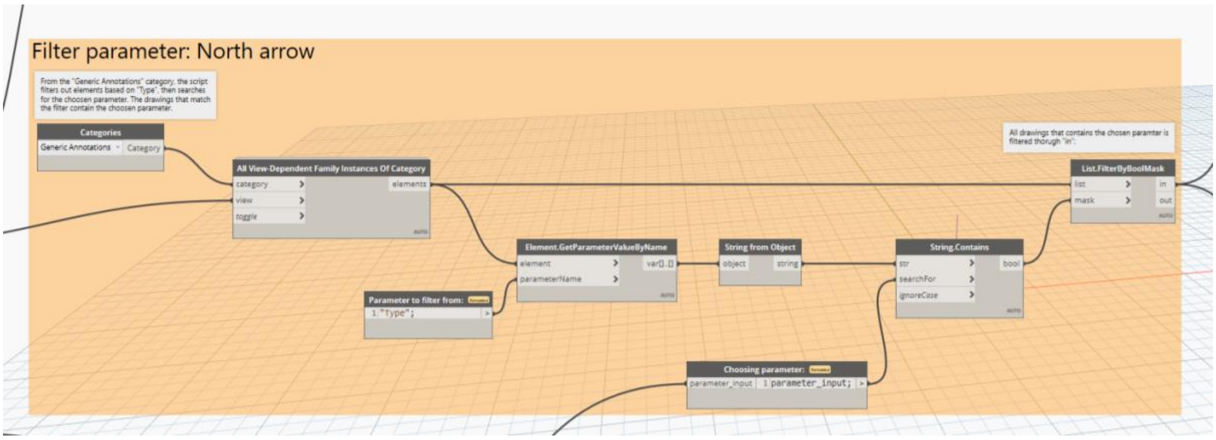

Figure 5: Step 3: Searching for North Arrows.

Step 4: Analyze the Angle of the North Arrow

This critical step involves checking whether the angles of the north arrows match the project's north angle as specified by the user, ensuring their accuracy.

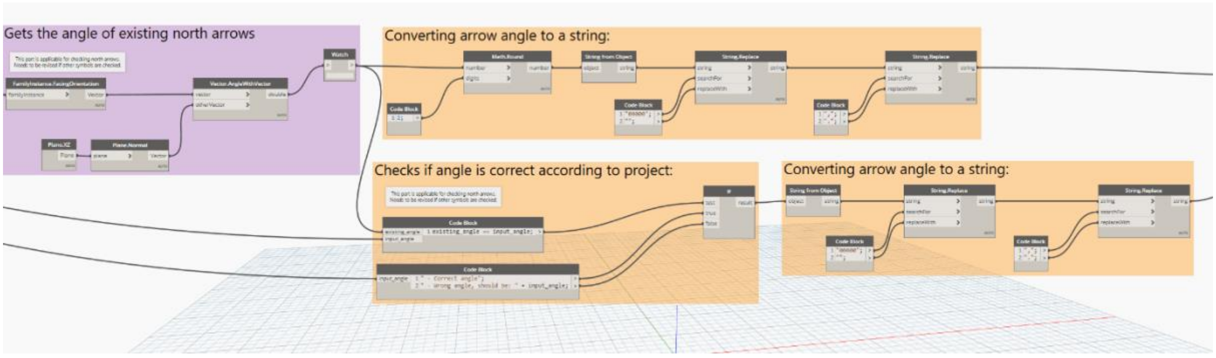

Figure 6: Step 3: Analyze the Angle of the North Arrow.

Step 5: Export Data to Excel

The final step involves exporting data concerning north arrows and their angles to an Excel file, providing a comprehensive overview of the presence and correctness of north arrows in the drawings.

Script 2: Error Correction

The second script is focused on addressing deficiencies by adding north arrows where missing and correcting their orientation to align with the project's north direction.

Error Introduction for Validation

To validate the effectiveness of these scripts, the model was intentionally modified to introduce errors, such as missing arrows and incorrect arrow angles. These errors were cross-referenced with the discrepancies reported by the scripts to ensure their alignment.

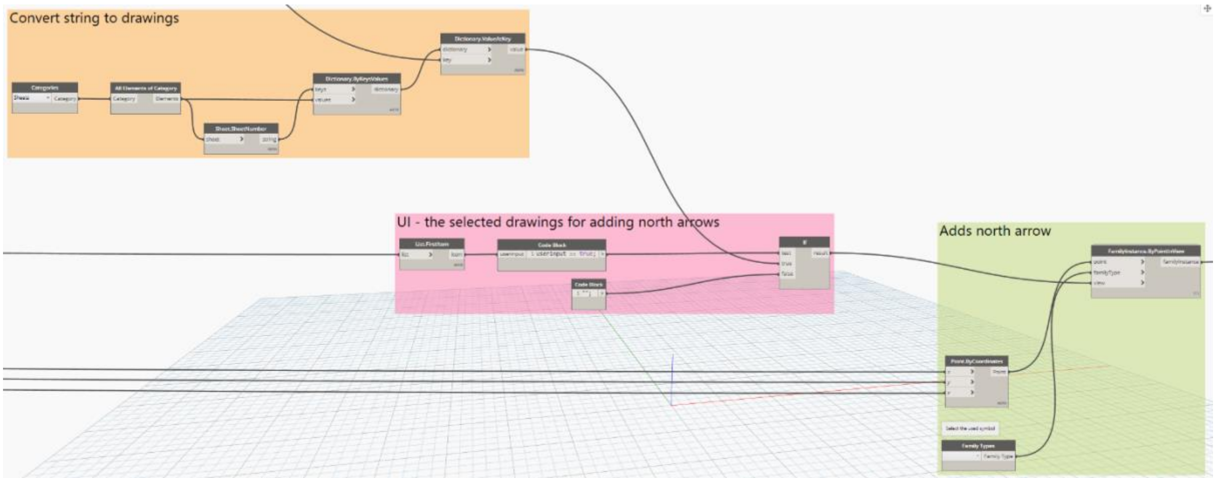

Figure 7: Step 3: Adding missing North arrow.

Unlike the first script, the fifth step in the second script is geared towards rectification; it appends north arrows to drawings where they are absent and adjusts their orientation accurately based on the specified north angle.

The comprehensive steps of both scripts, as well as their intended functionalities, are illustrated in detailed figures and descriptions in Appendix 1 and Appendix 2, respectively. This structured approach not only facilitates the precise alignment of architectural drawings with project specifications but also enhances the overall efficiency and reliability of the quality assurance process.

Figure 8: The five major steps of the second script are visualized as a flowchart.

3.4 Evaluation

The evaluation results for the scripts, grounded in assessments of their functional efficacy and user experience, are detailed subsequently.

Functionality: Concerning script functionality, a consensus was reached among all participants; they unanimously confirmed that the scripts performed their intended functions with precision, yielding the anticipated results. Moreover, the scripts complied with professional standards pertinent to architectural rendering. An interviewee further illuminated the potential for future enhancements, positing that while the scripts presently act as a proof of concept, they harbor the capacity for expansion, streamlining labour-intensive components of the drawing review process.

Usability: Concerning usability, the participants uniformly concurred on the scripts' accessibility, largely due to the provision of an accompanying user manual. Predominantly, two-thirds of the interviewees accentuated the user-centric design of the Dynamo Player, noting its facilitation of script execution, independent of the user's proficiency in visual programming. Nonetheless, a BIM Coordinator pointed out the prerequisite of a foundational understanding of visual programming to effectively operate the scripts within Dynamo and adapt them for diverse project demands. In unison, the BIM Coordinators acknowledged the inherent advantages of automating manual tasks—a paradigm shift that could significantly diminish the propensity for human error. *"Since it is important to disclose our workflow for quality assurance to our clients,*

The report that is created in Excel through the script is valuable." - Participant B2

Feedback: A BIM Coordinator articulated a suggestion for augmenting the user manual, advocating for the integration of a suggested workflow that delineates the procedures for the initial installation of the scripts as well as their daily operation. Moreover, the incorporation of directives for the customization of the scripts to accommodate a range of project specifications was recommended. The BIM Coordinator stressed the necessity for a clear demarcation between the actions required for a singular installation event and the actions necessary for regular script execution, ensuring that users maintain a clear understanding of the operational protocols.

4. DISCUSSION

According to Koo and O'Connor (2022), the attainment of high-caliber design outputs is pivotal to project success, accentuating the role of quality assurance and congruence with specified standards. Complementarily, Lee et al. (2019) expound on the propensity for errors and omissions during manual harmonization of regulations with design artifacts. This research was thus initiated to assess the viability of employing parametric design tools in fortifying the integrity of architectural drawings. The result is embodied in the development of two parametric design scripts that exemplify model artifacts, crafted to streamline and mechanize the compliance verification of architectural plans at a nascent stage of functionality.

The ISO (2005) and Hoyle (2009) posit that product quality is intrinsically linked to the fulfillment of specified criteria. While the scripts are dedicated to scrutinizing a singular parameter—the north arrow, recognized by Kim et al. (2022) as an integral component of drawings—they inadvertently enhance the overall product quality. However, it is imperative to acknowledge the scripts' limitations in providing exhaustive quality controls; additional project facets necessitate conventional verification techniques.

The scripts' inception stems from the interviewees' identification of the north arrow as a recurrent source of discrepancies. Kim et al. (2022) corroborate its classification as a fundamental element of architectural depictions. Addressing such a crucial component, the scripts ostensibly elevate three out of six quality metrics linked to tender documents—standardization, lucidity, and completion, as delineated by Govender et al. (2022). Moreover, the scripts adeptly target two error categories: omissions and regulatory non-compliance, as classified by Dosumu (2018).

Villaschi et al. (2022) discuss the propensity of parametric design to expedite workflow and bolster reliability. Conversely, Kim and Chin (2019) highlight the protracted nature of extracting drawings from BIM platforms, with an appended labor demand for refining extracts. The introduced scripts champion a parametric design-driven procedure, promoting efficacy and accuracy through automation, thus mitigating the human error factor, as supported by interview insights.

Parametric design is ubiquitously applied in preliminary design phases (Brown and Mueller, 2018); however, its utility for compliance verification is less traversed. Evaluative feedback indicates a unanimous preference among participants for an automated, visual programming-enabled compliance workflow, prizing the scripts' transparency and adaptability.

Di Guida et al. (2021) and Preidel and Borrmann (2018) distinguish between two software development paradigms: the opaque 'black-box' and the transparent 'white-box' approaches. The black-box, often associated with vendor-supplied solutions, offers reliability but lacks in adaptability and visibility. In contrast, the white-box method favors customization and transparency, conducive to bespoke development, facilitating script refinement to project-specific demands. The in-house deployment of such a method necessitates domain expertise and resources, and by virtue of its transparency, it inherently supports troubleshooting through the development phase.

5. CONCLUSIONS

Drawing from existing scholarship and findings from this study, it is clear that parametric design is adept at facilitating both quantitative and qualitative analyses. The scripts developed through this research exemplify how this technology can streamline the automation of compliance checks for drawing symbology, accessible even to those without prior experience in visual programming. Nevertheless, tailoring these scripts to specific project requirements might necessitate a fundamental grasp of visual programming. Additionally, both the literature and the outcomes of this study underscore an escalating interest in automating quality assurance processes, particularly in the context of drawing review.

In summary, the scripts developed serve dual roles tailored to distinct project functions. Script 1 is oriented towards error reporting and proves particularly beneficial for BIM coordinators by generating reports on detected issues without implementing corrections. In contrast, the synergistic application of Script 1 and Script 2, which is geared towards error correction, offers substantial value to designers. This combination allows designers to perform self-verifications, ensuring both the identification and rectification of discrepancies prior to the final submission of documents. This dual functionality underscores the scripts' utility in enhancing the accuracy and efficiency of project deliverables.

5.1 Limitations and Future Research

This research was dedicated to assessing the efficacy of parametric design in ensuring quality control within architectural 2D plan drawings produced during the design phase. These drawings were created using Autodesk Revit and assessed via Dynamo, a visual programming language (VPL) plugin tailored for Autodesk Revit. The empirical investigation was conducted within a Swedish context.

Looking ahead, potential research trajectories could delve into the market dynamics surrounding the provision of such scripts. Further exploration into the most effective deployment strategies—whether through external vendors or bespoke in-house development—is also merited. Given that these scripts contribute to enhancing workflow efficiency, it is pertinent to investigate how business models might evolve to support this shift towards automation. This consideration is crucial, especially given the implications of reduced billable hours for designers against the backdrop of heightened quality in project outputs. Moreover, broadening the scope of these scripts to include multiple parameters, varied types of drawings, and different disciplines represents a promising avenue for future inquiry, potentially expanding their applicability and impact across the architectural and engineering sectors.

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