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DAILY BATCH SIZE OF DESIGN – PROPOSAL FOR THE SIZING OF DESIGN BATCHES

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ABSTRACT

Lean construction techniques have effectively minimized batch sizes and lead times in construction production. However, the reduction of design batch sizes has focused on planning smaller tasks and has been quantified through the assessment of design hours, information packages, or design tasks. This work seeks to propose a practical method for determining batch size in design while simplifying and grounding ongoing theoretical discussions on the subject. The employed research methodology is a case study of four Finnish construction projects utilizing software created by researchers to estimate design batch sizes from industry foundation class (IFC) files. The primary outcome of the project is to demonstrate a method for visualizing the design batch size concerning added, removed, and updated building information model (BIM) components. The results indicate considerable diversity in design batch sizes and design data exchange cycles across different design disciplines and projects. This paper offers practitioners and academics a method to visualize previously concealed design batch sizes, facilitating batch size analysis as an initial step toward lowering these sizes.

KEYWORDS

Lean construction, design, batch size, building information model.

INTRODUCTION

Batch production is one step toward continuous flow. In a batch production process, a product or service transitions across departments (Holweg et al. 2018). In construction design, this product transition is evident when an architect conveys a building information model (BIM) or drawings to other designers (for example to structural designer), who then proceed with their respective tasks. A notable characteristic of design work is the flow of information, wherein the output generated by one design participant serves as the 'raw material' for subsequent stages of the design process (Tribelsky & Sacks, 2010).

Similar to the manufacturing sector, the building design sector has begun to explore methods for minimizing batch sizes (Ballard et al. 2007). For decades, the manufacturing sector has

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noted the detrimental impacts of substantial batch sizes, including increasing idle time, excessive overproduction, enlarged inventory, delayed identification of batch defects and production system rigidity (Womack & Jones, 1997; Brown et al., 2006). Similarly, the building design sector has attempted to mitigate these negative effects (Ward & McElwee, 2007; Tribelsky & Sacks, 2010; El. Reifi & Emmitt, 2013). Designers have recognized the necessity for smaller batch sizes; however, design work continues to be executed in relatively large batches (Bulhoes & Picchi, 2008; Lappalainen et al., 2021).

The reduction of batch sizes in construction works has resulted in decreased lead times (Binninger et al., 2018; Kozlovská & Klosova, 2022), and the reduction of design batch sizes is anticipated to further diminish the overall lead time of the entire construction project. Although minimizing batch sizes in design is anticipated to have economic advantages, there is still a lack of academic research that addresses the practical needs of designers (Agrawal et al., 2024; Moradi & Sormunen, 2024). The batch size of design work has been quantified through the assessment of design hours, information packages or design tasks (Tribelsky & Sacks, 2010; Demian & Walters, 2014; Lappalainen et al., 2021). Currently, BIM-based design work predominantly occurs within BIM models. BIM facilitates the integration and coordination of multiple design disciplines (Sacks et al. 2018; Disney et al. 2022). Thus far, research on design batch size based on BIM has been notably scarce (Saygili et al., 2019).

This study employs a practical tool created by researchers to analyze batch sizes in design utilizing industry foundation class (IFC) files exported from BIM. The research specifically seeks to examine 1) the batch sizes utilized by various design disciplines, 2) the distinctions among them, and 3) the temporal variations in design batch sizes. If batch size cannot be quantitatively measured, achieving a reduction in batch size is challenging. Justifying batch size reduction in design and construction firms also becomes problematic. Therefore, this study seeks to concretize the somewhat abstract concept of design batch size in relation to actual design work, management, and development while offering practitioners recommendations for achieving completely automated batch size measurement.

METHOD

The study was carried out as a case study (Yin, 2009). The data were gathered from four Finnish construction projects that reached the detailed design phase. The first case evaluated four design disciplines (architectural, structural, HVAC and MEP, and electrical). The second case evaluated three design disciplines (architectural, structural, electrical), while the latter two projects (retail shop projects) focused solely on structural design. Only the structural design model of the retail shop buildings was provided to the researchers, as only the structural design firm engaged in the study. Table 1 presents the case descriptions.

The researchers created a software application to quantify the additions, deletions, and geometric modifications of elements in IFC-formatted BIM files. Statistics were made on how many model parts were added, removed, moved, or had their shape and geometry changed for a real case study project. Software took a set of IFC models and used the kernel of IFC class files into the linked building data ontologies (IFCtoLBD) kernel (Bonduel et al., 2018; Oraskari et al., 2023; Oraskari et al., 2024) to read the models' semantic information. The IfcOpenShell optimized Open CASCADE geometry kernel was then used to make a triangulation out of the IFC geometry. The models were ordered by the timestamps of their exports and resampled to create a uniform timeline.

Table 1: Case descriptions.

Case	Description
1	Workshop building. The building was part of a larger industrial building project and housed the factory’s spare parts service, a repair workshop, and working and changing rooms for the workers and supervisors working in the building. The project was owned by a large forest industry company, and the construction, design coordination, and management of the project was carried out by a construction management consultant. The building also included a bomb shelter. The project designers were all from the same engineering firm. The BIM models of the architect, structural engineer, HVAC engineer, and electrical engineer were analyzed. The architect had 7 different versions of IFC files, the structural engineer had 59 versions, the HVAC engineer had 31 versions, and the electrical engineer had 10 versions. The gross area of the building is 3300 square meters.
2	University building. The project is a university construction project managed by a public company that owns the university real estates. The company implemented the project through a project management contract with the contractor responsible for coordinating and managing the design. The BIM models of the architect, structural engineer, and electrical engineer were analyzed. The architect had 48 versions of IFC files, the structural engineer had 32 versions, and the electrical engineer had 46 versions. The gross area of the building is 27,300 square meters.
3	Retail shop building. The building was a new building for a chain of retail stores, which served as a retail shop and housed staff facilities for the store’s employees and supervisors. The project was carried out by the contractor as a lump sum contract at a fixed price, with the contractor responsible for coordinating and managing the design. The structural designers for the project were all from the same structural design office. 13 structural engineers' IFC file versions were analyzed. The gross area of the building is 9400 square meters.
4	Retail shop building. The building was a new building for a chain of retail stores, which served as a retail shop and housed staff facilities for the store’s employees and supervisors. The structural designers of the project were all from the same structural design office. The building is almost identical in layout to Case 3 and was designed consecutively for the same client. The project was carried out using the same main contract model and implementation method as in Case 3, with the client coordinating and leading the design. 16 structural engineer's IFC file versions were analyzed. The gross area of the building is 8200 square meters.

Global unique identifiers were generally used to help the parts keep track of the changes. Triangular meshes with rounded coordinate values were used to track the geometry changes. This rounding adds tolerances so that only actual modifications are counted. These triangles were ordered to ensure that the checksums reflected all serializations of the shape geometry. Then, the MD5 message-digest method checksums were calculated at different times for each element’s shape. These data were grouped and used to find the total number of elements that were added, removed, or changed in shape to make line charts showing the statistical changes in the timeline of the series.

The results were reported in one Microsoft Excel sheet per design discipline. One Excel sheet was used for each domain to show the results. An Excel file was exported from the software and subsequently manually analysed using Excel and Minitab 22.0 software. Using Minitab, the design batch size was calculated for the absolute daily value and the value divided by the gross area of the building. Minitab was also used to calculate descriptive statistics and box plot graphs.

The design batch size for this study was established as the modifications, additions, and deletions made to each design discipline between exported BIM model versions. Daily design batch sizes were estimated by dividing the variations between versions by the number of calendar days separating those versions. Since the researchers did not know the time between the start of the first BIM model version delivery and the start of the modelling work, in each case, the number of elements of this first BIM version was divided over five days, assuming that five working days would have elapsed between the start of the modelling and the delivery of the first model version. The frequency with which designers exchanged BIM models was also examined (Ballard, 2000). This was accomplished by computing the differences in calendar days between the release dates of the model versions.

FINDINGS

The findings are displayed in Table 2 and Figures 1 to 5. Table 2 presents the descriptive statistics for the collected data.

Table 2: Case statistics of daily design batches.

Cases	Versions	Mean Modified Elements	StDev	Minimum	Q1	Median	Q3	Maximum
CASE 1 ARC	7	101,7	165,1	5,3	7,2	29,1	166,2	454,0
CASE 1 STR	59	39,6	50,4	0,0	0,0	17,8	72,1	199,1
CASE 1 HVAC	31	164,2	201,1	0,0	20,7	76,0	238,5	710,0
CASE 1 ELE	10	19,4	31,6	0,5	1,5	2,4	35,9	92,4
CASE 2 ARC	47	125,8	251,2	0,0	30,5	49,9	95,9	1288,3
CASE 2 STR	31	293,6	410,3	3,6	43,2	176,9	301,7	1799,0
CASE 2 ELE	45	120,1	110,0	0,6	51,9	85,9	147,4	445,9
CASE 3 STR	13	53,2	58,9	0,1	9,4	28,7	92,2	182,0
CASE 4 STR	16	17,9	32,4	0,0	1,1	5,4	21,4	132,4

Figures 1 and 2 illustrate the fluctuation in the daily batch size of design by case, presented as a box plot. Figure 2 illustrates the impact of changes in building size. Figures 3 to 5 illustrate the fluctuations in daily design batch size across various versions of the BIM model over time.

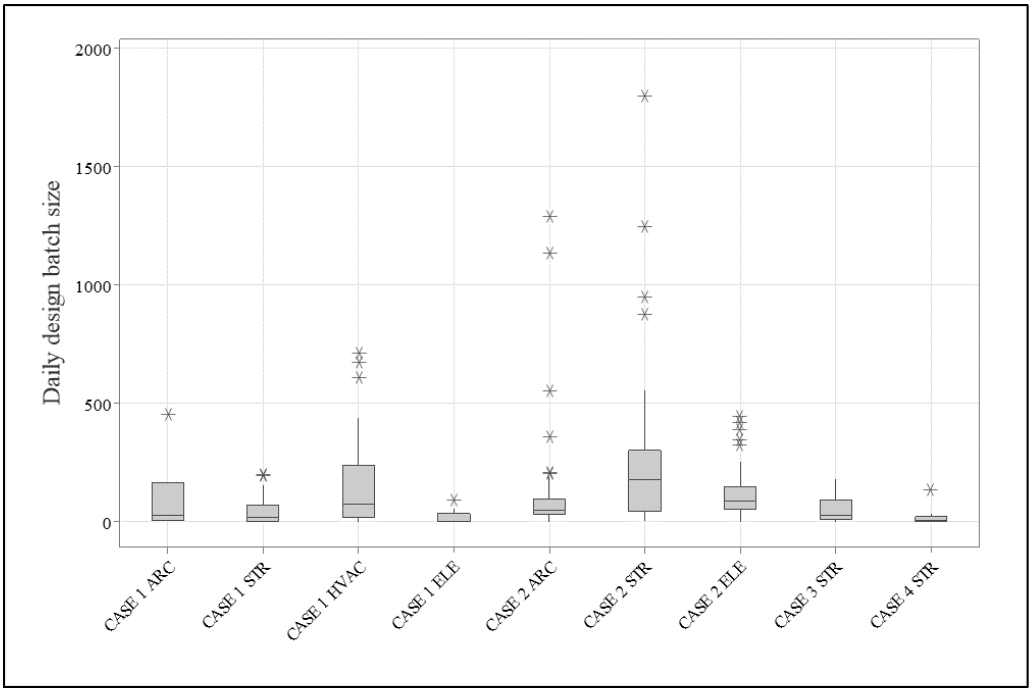

Figure 1: Daily design batches, absolute values.

Table 2 and Figure 1 indicate that the mean daily design batch size exhibits considerable variability, ranging from 17.9 to 293.6. The most substantial daily design batch sizes were recorded in the architectural design of the largest case 2 by area, with a maximum daily batch size of 1288, and in the structural design, where the maximum daily batch size reached 1799. The minimum mean design batch size was observed in the structural design of Case 4 at 17.9 and in the electrical design of Case 1 at 19.4. The standard deviation of the design batch size was largest in the structural design of Case 2.

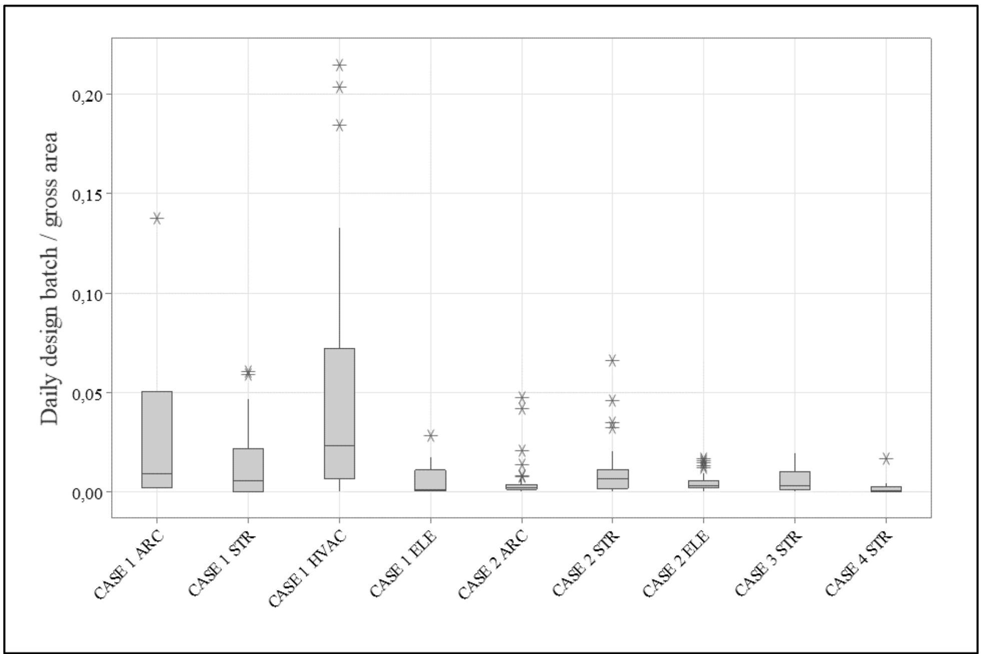

Figure 2: Daily design batches relative to gross area.

Figure 2 illustrates the relative disparities in the size of the design batch across various design disciplines and cases more distinctly than Figure 1. In structural design, the design batch size appears to be smaller compared to other design domains; however, in HVAC and MEP design, the batch size is significantly larger, accompanied by greater variability. Case 2, the most extensive case by gross area, exhibits a reduced batch size for architectural design compared to Case 1, which encompasses a smaller gross area. The electrical design features a minimal batch size. Figures 3 to 5 illustrate the fluctuation in daily design batch size over time by design discipline, which is predominantly elevated in the initial half of the detailed design period but diminishes considerably in the latter half.

The most significant variability in model version sharing occurred in the architectural and electrical designs of Case 1. The typical release intervals ranged from 7.2 to 53.4 calendar days, depending on the design domain. On average, a model version was published every 15.6 days, with a standard deviation of 20.9 days. The median distribution interval for model versions was 8 calendar days.

The study found several challenges with batch size in design that practitioners and scholars researching and aiming to reduce batch size should recognize. First, considerable variability exists in design batch sizes, contingent on the design discipline. Analysis by design discipline indicates that HVAC, MEP and architectural design are conducted in larger batch sizes than structural and electrical design. Second, the design batch size is variable and fluctuates over time. In the early stages of design, as each designer constructs the BIM model, the design batch size increases. It decreases in later stages as completion approaches. Third, there is significant variability in the distribution of BIM models to other design stakeholders. The subsequent discussion focuses on these findings.

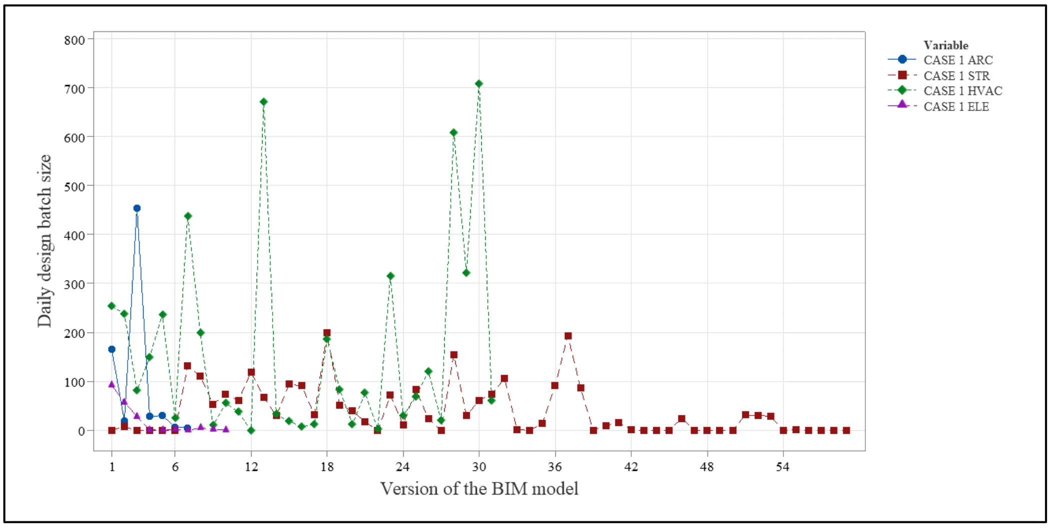

Figure 3: Daily design batches over time. Case 1.

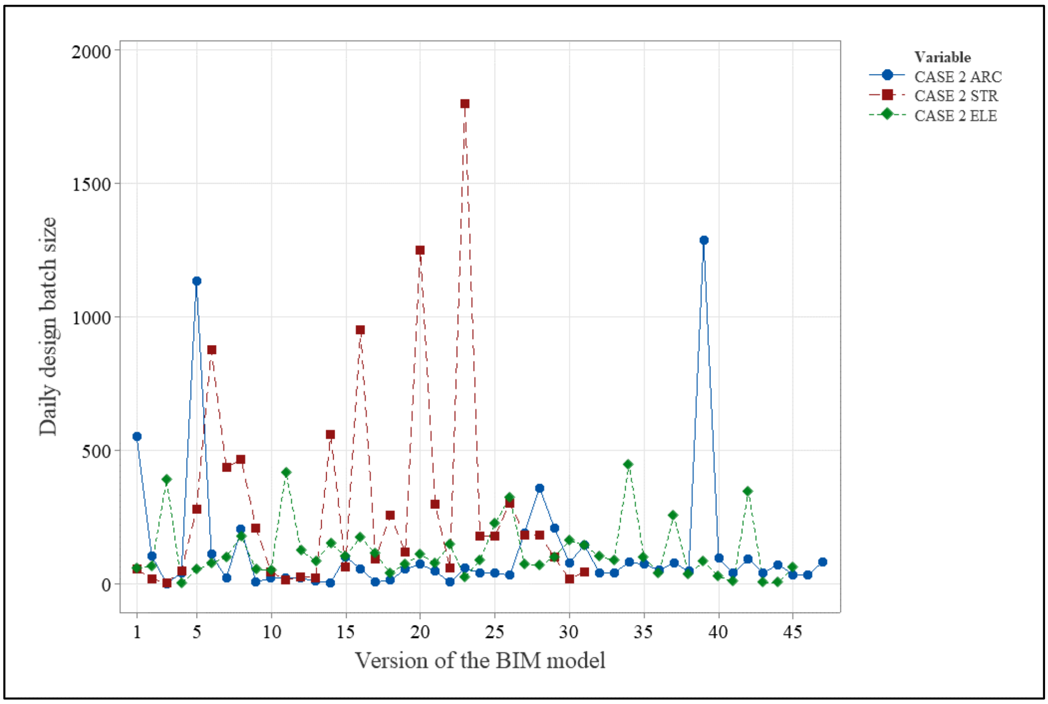

Figure 4: Daily design batches over time. Case 2.

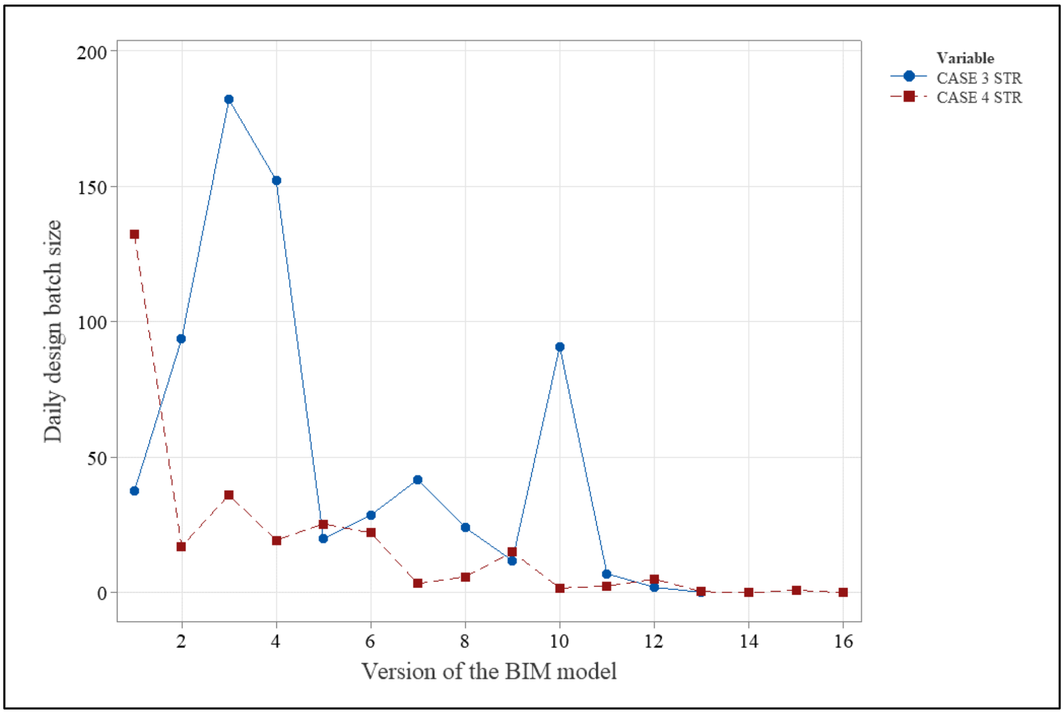

Figure 5: Daily design batches over time, Cases 3 and 4.

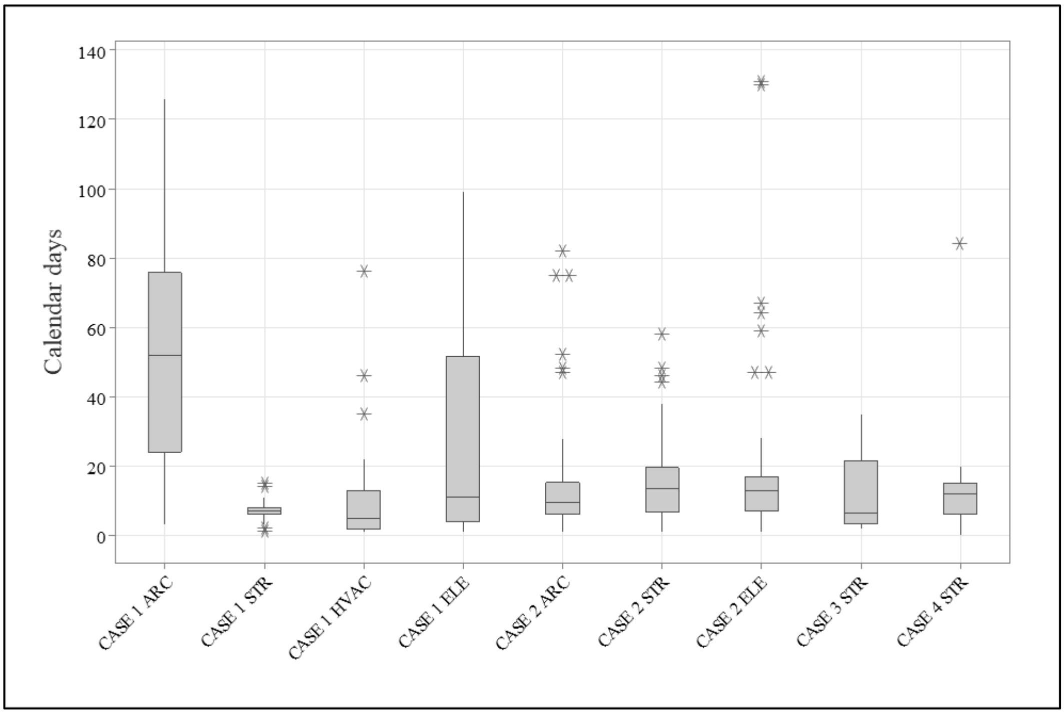

Figure 6: Frequency of publication of model versions on calendar days.

DISCUSSION

Ballard (2000) proposed that substantial advantages can be attained by minimizing design batch sizes and disseminating design knowledge in smaller increments. This includes halving design time, diminishing the frequency of coordinating meetings, and enhancing the transparency of the design process (Ballard, 2000). This aligns with the ideas of lean thinking, wherein small batches mitigate bottlenecks and the aggregation of errors throughout the process (Womack & Jones, 1997). This study has demonstrated a method to visualize design batch size by analyzing

BIM model versions, revealing significant variance in batch size between design domains and in the distribution of information via IFC files. Automation of the method used is feasible, and we assert that transparently conveying the design batch size and frequency of BIM model data sharing to design teams and design management would serve as a foundation for initiatives aimed at minimizing batch size.

This limited data of this study generates more questions than it resolves. What is the suitable batch size to target for each project type or design discipline? This study's data raises the question of whether it is sensible to pursue a consistent design batch size over the entire design period. Potentially, the design batch size should vary depending on the design phase; therefore, subsequent research should investigate how the level of detail and the design phase affect optimal batch sizes.

One might also consider whether it is more prudent to prioritize enhancing the stability of the design process before attempting to reduce batch size. The significant heterogeneity in BIM model distribution may be regarded as a bottleneck in the design process, raising the critical question of whether the BIM model distribution cycle may be further expedited. The data indicate that BIM models are typically transferred every 1-2 weeks, with sporadic extended intervals between sharing. This will undoubtedly impact other designers, and prolonged delays may necessitate a revision of the design process when obsolete information is utilized.

The initiative to minimize design batch sizes aligns with the objective of lean construction to diminish variability in the design process and to transition design work towards the continuous-flow model commonly observed in manufacturing (Uusitalo et al. 2019; Tribelsky & Sacks 2011). Despite little research on batch size in design, data suggest that reducing batch size similarly decreases design lead times, as observed in manufacturing (Ballard, 2000; Lappalainen et al., 2021). However, batch size is inherently subjective across various building projects and optimizing it may have limited effects on the value provided to the owner or end-user, often established prior to the detailed design phase. From the standpoint of individuals involved in the final stages of construction, batch size computation and optimization may provide innovative approaches to the design process, making it pertinent and beneficial for designers, builders and potentially certain categories of owners. This work enhances the comprehension of the current batch size in design and elucidates how its variation may be discerned from BIM models. Given the apparent discrepancies in batch size across design disciplines, we advocate additional research to examine the design processes and practices across these disciplines to ascertain the factors influencing design batch size variation.

LIMITATIONS

The primary limitation of the study is the limited number of cases and their exclusive concentration in Finland. This study, based on only four cases, is an exploratory experiment on a new method to estimate the design batch size, and the results of the study are not generalizable and require more cases for further research. There were also differences among the cases; specifically, cases 3 and 4 contributed less than cases 1 and 2. For further research, there is a need for additional data from cases encompassing all disciplines involved in the design process.

Another significant limitation of the study is the researchers' lack of specific information regarding the coordination and management of design as well as how variations in these parameters may have influenced the batch size of design or the cycles of BIM model sharing. Likewise, certain elements within project timelines may contribute to delays in BIM model delivery, which may not be attributable to the designers themselves. In addition, the quantity of modifications applied to each model version does not inherently dictate the batch size; certain versions may exhibit minimal alterations yet entail substantial adjustments, and conversely.

In addition, the utilization of calendar days streamlines calculations in this study, although it diminishes the batch size of design relative to a scenario where design occurs solely on weekdays. It is important to acknowledge that the researchers were unaware of the specific days of the week on which the design work occurred between the delivery dates of the BIM model versions, rendering all estimates partially imprecise. Nonetheless, the inaccuracy in this regard pertains to all design disciplines and cases, yet it does not hinder the research questions from being addressed with adequate precision. In further research, an analysis of the logs of the native files of the design software may eliminate this inaccuracy.

One limitation was the absence of component-level data in this investigation. When decreasing the design batch size, it is essential to recognize the many design elements and their possible effects on batch size fluctuations. Another component-related limitation of the method used in this study is the batch size definition, which does not consider the differences in the size of the model components. The component level, along with the associated alterations and batch sizes, will be examined later in this research project.

The modifications in design batch size also omit the assessment of variability and the underlying causes of substantial batches, which can be automated, at least in a major part. We assert that there exists a demand for such programmatic analysis, which is essential for large-scale BIM models due to the arduous nature of root cause analysis (Lappalainen et al., 2023). However, the large fluctuation in the number of changes observed in the study, both between versions and between disciplines, may also lead to potential misunderstandings, which is important to consider when seeking to standardize the daily batch size of design in future research.

A technical BIM quality issue affecting the created code is the necessity for the GUIDs of model objects to remain constant, ensuring that the code functions correctly and maintaining control over object traceability. This can be regulated in the IFC export configurations of the design software. Furthermore, the recent emergence of parametric design may facilitate the substitution of GUIDs with more conventional design methodologies. The generated code does not necessitate any explicit quality requirements; however, the enhanced quality of the IFC attributes (locations, floor, building, building types: wall, slab, beam, column) would yield more precise output from the code. The variation in object types across versions is crucial for the batch size analysis discussed in this research, as such changes indicate a significant qualitative issue.

Of course, there is more to design dynamics and batch size information than how this study automatically determines changes in IFC files. A lot of data is sent back and forth during the design process that does not go through BIM models or even the design software itself (Tribelsky & Sacks, 2010). The study also does not consider the complexity of all design processes. The design process, particularly in its first conceptual phases, is a creative endeavour that often consumes significant time, and it cannot be adequately represented solely through the analysis of BIM data using the code developed for this study. Also, the extent of standardization of the design process and products may influence the design batch size. Regrettably, at this juncture of the investigation, it was unfeasible to acquire data or a precise comprehension of the variability in the level of standardization among these cases. To obtain an answer, it would be beneficial to utilize the code created for examining offsite fabrication and prefabrication, which fundamentally standardizes design solutions, particularly for precast concrete and steel structures. This will be considered in the subsequent study. We are aware of these limitations in our study and would encourage scholars and practitioners to do similar studies in which the design batch size information in the IFC files is expanded to include other IFC parameters and mixed with other digital information circulating around in the design process.

CONCLUSION

The study's aim was to make the design batch size more visible and concrete and to help scholars and practitioners align their ideas on how to reduce the design batch size with realworld data and findings. The study also pointed out an automatic way to determine the size of the design batch by calculating added, changed, or removed BIM model objects from different versions of IFC files. It is possible to cut down on lead time, design coordination time, and the lack of transparency in the design process by increasing the size of the design batch (Ballard, 2000), and this study contributes to providing further insight into a topic with limited previous research.

The primary conclusion of this study was that IFC files could be utilized to examine and analyse the batch size of a design. The findings indicated that the dimensions of the design batches varied among the design domains, along with associated temporal changes. Design batch sizes appeared to be significantly larger during the initial phases of design, accompanied by greater variability in these sizes during this period. A comparable difference in BIM model distribution by design area was noted, and these case projects facilitated an estimation of the practical distribution interval for BIM models, discovered to be between 1 and 2 weeks.

The study's results demonstrate how the batch size of a design can be systematically evaluated through the analysis of IFC files. Our proposed methodology offers a means to determine the design batch size in practical projects, such as estimating it based on data from prior projects and establishing targets for the batch size across various design domains. This may involve adhering to a trend of progressively decreasing batch size as the project advances or enhancing the stability of BIM model distribution. Our proposed method for automating batch size analytics facilitates the optimization of design by reducing the laborious manual analysis of design tasks.

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