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Study on Front-Loading Utilizing Engineering and BIM in Steel Fabricators

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Abstract: In Japanese steel fabricators, significant time is devoted to drafting fabrication drawings compared to the fabrication process itself, highlighting a need for efficiency improvements. A primary issue is the inadequate consideration of constructability at the design stage. Steel fabricators often sign contracts based on partially completed designs, leading to frequent modifications from the creation of fabrication drawings up until just before fabrication begins, which hampers productivity improvements. To address this challenge, this study proposes separating and contracting engineering from fabrication early in the design phase through front-loading detailed design. If front-loading is feasible, it could reduce the frequency of changes and corrections, improving the drawing process and potentially enhancing efficiency in steel fabricators. Furthermore, the study explores what constitutes feasible engineering for front-loading, considering that steel fabrication involves aspects beyond mere structural design.

Key words: Steel fabrication, Fabrication drawings, Engineering, Front-loading, Productivity

1. INTRODUCTION

In many foreign countries, fabrication drawings for steel structures are created by Structural Engineers (SE) or Assistant Engineers (AE), whereas in Japan, these drawings are produced by steel fabricators who also perform the manufacturing. Additionally, in Japan, details are not thoroughly examined at the stage of ordering from the prime contractor (general contractor), and the examination of details occurs during the construction phase, leading to frequent design changes at this stage. Steel fabricators contract with general contractors and receive structural drawings as necessary information for steel fabrication. They interpret these to create fabrication drawings, broadly categorized into general arrangement drawings *1, reference drawings *2, and detailed drawings *3 [1]. Furthermore, specific drawings for cutting, drilling, and other specialized tasks, known as "fabrication detailed drawings," are created for actual fabrication. The creation of these drawings requires more time compared to fabrication, with a primary issue being the insufficient consideration of constructability at the design stage. Additionally, there is often inadequate coordination between structural designers and architects or MEP (Mechanical, Electrical, and Plumbing) designers regarding facades and routing of MEP services. Moreover, there are instances where the details of ancillary steel elements, which are part of the steel product but affected by the scope of work of other specialty contractors, are not decided until just before fabrication. To resolve these issues, exchanges of inquiries and answers take place, but since steel fabricators contract directly with general contractors, they do not engage directly with other parties. In Japan, the process of inquiries and answers is comprehensive, involving the exchange of documents that cover all aspects, leading to significant time consumption until the resolution of each issue. Additionally, design changes occurring just before fabrication necessitate the allocation of substantial manpower for revisions, contributing to inefficiencies in steel fabrication, particularly in the creation of fabrication drawings [2][3].

In Japan, constructing a building requires approval called a "confirmation application," based on the Building Standard Law, primarily focused on verifying structural safety, with little mention of constructability or fabrication. Thus, structural drawings created for review often lack sufficient consideration for steel fabrication. These drawings are issued to steel fabricators through general contractors after contracts are signed, making various engineering tasks related to steel fabrication the responsibility of steel fabricators after contracts with both the client and general contractor are finalized. Many inquiries are directed towards designers, and their routing through general contractors contributes to inefficiency.

One method to improve the efficiency of drawing creation is through front-loading, which involves increasing the level of design details early on, considering constructability and manufacturability. Front-loading in the construction industry is defined as incorporating the client's needs early in the project, advancing decision-making (consensus building) from the design stage with the client, designer, and contractor working together to reduce downstream hold-ups, rework, and adjustments, thereby reducing the overall workload, and building in quality, cost, and schedule improvements [4]. In steel fabrication, this includes evaluating structural details such as plate and bolt placement and welding from the perspectives of construction and fabrication, as well as considering non-structural design aspects like facade support methods and MEP penetration treatments. This approach can potentially reduce the number of post-order inquiries, answers, and design changes. Additionally, in recent years, the lead time for material procurement has extended [5], with some steel types requiring up to a year from reservation to procurement. Therefore, steel fabricators need to accurately understand the required quantities at the time of reservation, and increasing detail level at the design stage can also help avoid procurement risks due to quantity discrepancies between reservation and final order.

Against this backdrop, this study aims to:

1. Analyze and redefine the tasks of steel fabricators, classifying them into engineering and fabrication.
2. Analyze engineering that can be front-loaded and propose methods for efficiency improvement.

2. REVIEW OF PREVIOUS RESEARCH

The various issues in the steel fabrication process in Japan have been the subject of numerous studies. Kanisawa et al. [3][6] analyzed documents such as meeting records between general contractors and steel fabricators in the 1990s to elucidate the realities of production design and construction method planning, shedding light on the process from design to fabrication. Umekuni et al. [7] categorized the division of labor in the steel fabrication process based on the business types of steel fabricators into modular types, with little interdependence, and integral types, requiring coordination. Through their research, they clarified the characteristics of each business type based on their procurement behaviors. Kim et al. [8][9][10] conducted research in the 2010s analyzing the steel production process, focusing on the impact of design changes on steel fabricators. They identified the causes of design changes and the methods and challenges of dealing with them in steel fabricators.

However, while these studies focus on the details and characteristics of the steel production process, research on the efficiency and information utilization of drawing creation, especially focusing on front-loading, is limited. Therefore, this study aims to analyze the engineering tasks of steel fabricators and clarify the methods and challenges of efficiency improvement through front-loading.

3. METHODOLOGY AND OVERVIEW OF THE STUDY

This study categorized tasks into engineering and fabrication based on the fabrication process of steel fabricators and conducted an analysis of their operations. Based on this analysis, a survey was conducted regarding the drafting tasks that could potentially be front-loaded. The survey was distributed in advance, featuring both multiple-choice and open-ended questions. Following preliminary considerations by each company, interviews were conducted either face-to-face or via web conference, during which the responses were verified. These interviews took place from October 19th to October 25th, 2023. For topics deemed to require additional interviews during the analysis, follow-up investigations were conducted via email.

A prerequisite for implementing front-loading identified in this study is the use of dedicated steel CAD software [*4], and it is hypothesized that, in the future, efficiency in drawing creation could be enhanced through integration with structural BIM. Therefore, the survey targeted steel fabricators that are proactive in utilizing digital data and those with extensive in-house knowledge of drawing creation, with five companies being selected for participation. An overview of the selected five companies is presented in Table 1.

Table 1. Overview of Fabricators Surveyed.

Company	Location	Grade	Interview Date
A	Tochigi Pref.	S	June 12 (Preliminary, in-person) October 19 (Web)
B	Niigata Pref.	S	October 20 (Web)
C	Yamaguchi Pref.	S	October 25 (in-person)
D	Iwate Pref.	H	October 23 (Web)
E	Kumamoto Pref.	S	October 19 (Web)

Furthermore, to clarify the challenges from drawing creation to approval, a web conference involving structural designers, steel fabricators, and drafting companies was held on December 13th, 2023. This meeting, aimed at discussing the use of digital data for steel detailing, was conducted during the committee's time dedicated to this purpose, with three structural designers, two steel fabricators, one drafting company, and two vendors of dedicated steel CAD software participating.

4. ANALYSIS OF STEEL FABRICATION PROCESSES IN STEEL FABRICATORS

The steel fabrication process in Japanese steel fabricators is conducted based on the division of roles across multiple departments. A detailed analysis of this process explores the possibilities for efficiency and optimization within the fabrication process. In this analysis, based on literature [11], the main tasks related to steel fabrication and their responsible departments were identified and categorized as shown in Table 2. Furthermore, the survey results regarding fabrication drawings revealed the perception of steel fabricators towards the engineering process, as indicated in Table 3.

Table 2. Overview of Fabricators Surveyed

Task	Sales	Technical	Manufacturing	Construction Management	Quality Control	Procurement	Engineering
Review of Structural Drawings	x	x	x	x	x	x	
Cost Estimation, Quoting	x	x					x
Contracting	x						
Creation of Fabrication Manuals		x	x	x	x		
Inquiry Preparation	x	x	x				x
Fabrication Drawing Creation		x					x
Actual Size Measurement		x					
Material Procurement						x	
Fabrication			x				
Product Inspection					x		

Based on these results, this study defines "Cost Estimation and Quoting," "Inquiry Preparation," and "Fabrication Drawing Creation" as the main components of steel engineering, focusing on these tasks. In particular, "Cost Estimation and Quoting" and "Fabrication Drawing Creation" are considered essential processes for the success of a project, contributing to the productivity improvement of steel fabricators by combining technical insight with economic evaluation. The task of inquiry preparation involves both the technical and manufacturing departments, implementing a comprehensive consideration of fabrication and construction elements. This process is vital to ensure that fabrication drawings accurately reflect design and site requirements, resulting in improved accuracy of quotes and fabrication drawings.

From this analysis, the significance and interdependence of each task within the steel fabrication process become apparent, suggesting directions for improvements towards efficient project execution.

Table 3. Responses Regarding the Engineering Process in Steel Fabricators

Company	Cost Estimation	General Arrangement Drawings	Reference Drawings	Detailed Drawings	Fabrication Detail	Procurement	Others
A	x	x	x				
B	x	x	x	x			
C	x	x	x	x	x	x	
D	x	x	x	x		x	Quality planning, Process planning
E	x	x	x	x		x	Manufacturing technology development, Transportation planning, Construction planning

4.1. Analysis of Cost Estimation and Quoting Activities

In Japan, steel fabricators typically use dedicated steel CAD software to calculate quantities and submit quotes to general contractors based on those calculations. This specialized CAD software creates three-dimensional steel model data that includes specifications from detailed structural drawings and reference drawings indicating special specifications [*5] and common details. The model data is not only used for quantity calculation but is also utilized in the creation of fabrication drawings, contributing to the efficiency of the creation process. However, structural drawings are often created using two-dimensional CAD, and the opportunity to link structural models with attribute information from BIM authoring software to specialized steel CAD is rare [12]. This situation is partly due to the increasing practice of linking "integrated structural calculation software" [*6] with BIM authoring software to create structural drawings. However, the attribute information described in BIM authoring software varies among companies, and the lack of standardization makes it difficult to transfer to specialized steel CAD.

Concerning the amount of information specified in special specifications and reference drawings, there are opinions that the current representation is adequate. However, issues have been pointed out, such as the inability to fully reflect unique details in reference drawings and the insufficient variety of reference drawings. Additionally, it has been noted that reference drawings, which are reused across different projects, are not updated even after repeated inquiries and responses [11]. Increasing the variety of reference drawings and enhancing their detail level could reduce the cycle of inquiries and responses caused by unclear drawings, potentially leading to efficiency improvements in quantity calculation and fabrication drawing creation.

4.2. Analysis of Fabrication Drawing Creation Activities

Survey results revealed that creating fabrication drawings takes three to five times longer than the actual fabrication process. This underscores the critical importance of enhancing the efficiency of fabrication drawing creation in steel fabricators.

Especially for drawings that can be generated by adding information to structural drawings, such as general drawings and reference drawings, there is significant room for improvement due to the current underutilization of digital data from structural drawings. The survey inquired whether the information provided in structural drawings is currently sufficient, with many companies indicating a deficiency of information in both general drawings and reference drawings, as shown in Table 4.

Table 4. Specific Items Lacking in General Drawings and Reference Drawings

Company	General Drawings	Reference Drawings
A	Insufficient detail on fittings, Discrepancies between architectural and structural drawings	Insufficient detail on fittings
B	Specification of member positions when eccentric	Lack of joint information
C	Placement of smaller beams, Lack of information on ancillary steel	Lack of welding instructions, Insufficient special fitting details
D	Insufficient detail on fittings, Design not feasible for fabrication	Reference drawings not matching the project
E	Discrepancies between architectural and structural drawings, Lack of information on secondary members	Insufficient special fitting details such as patented methods

For general drawings, there was a noted shortfall in information regarding secondary members like smaller beams, intermediate columns, and wind-resistant beams. This issue may be partly due to the use of "integrated structural calculation software" unique to Japan for verifying structural safety. Within this framework, although secondary members are input as components for load transmission to beams and columns, they are verified for structural safety separately from the software. This leads to issues such as incorrect representation of location information in structural drawings and treatment of members solely as loads, with actual placement often omitted. As a result, details must be clarified through inquiries, contributing to the identified information gap.

Inconsistencies between architectural and structural drawings for general drawings were also highlighted. Despite being a longstanding issue, the predominantly sequential nature of design task handovers has hindered progress in resolving these discrepancies. Although collaborative editing environments like BIM and cloud services are available, the lack of a concurrent workflow impedes the ability to promptly verify changes with each other, thus acting as a barrier to the efficiency of fabrication drawing creation in steel fabricators.

Concerning reference drawings, there were criticisms regarding the lack of variety and often inaccurate indications of their applicability. It is common in Japan to reuse reference drawings from previous projects without modification, resulting in materials that are mismatched for the current project. Therefore, the current approach involves verifying details through inquiries. Creating necessary reference drawings based on "fitting studies" and clarifying their applicability could lead to more efficient fabrication drawing creation in steel fabricators.

Structural drawings sometimes represent special fittings as two-dimensional detailed drawings, but they are not always created with the necessary level of detail required for fabrication in mind. On the other hand, fabrication drawings created by steel fabrication companies need to be made with factory processing in mind and on a fabrication unit basis, requiring the adaptation of information from structural drawings. Additionally, it has been pointed out in follow-up interviews that, even when fabrication drawings are created in structural design, there has been a tendency to reduce the creation of such drawings compared to before, due to modifications making them more fabrication-friendly for steel fabricators. Consequently, steel fabricators are moving towards a workflow where fabrication drawings are created after "fitting studies" to consider constructability and manufacturability, and then approved by structural designers. The creation of fabrication drawings includes aspects such as beam penetration reinforcements and elevator reinforcements, with the structural designer being the final approver of the fabrication drawings. However, interactions often required with parties other than structural designers, and these interactions are typically carried out sequentially through general contractors, hindering efficiency.

5. FRONT-LOADING ANALYSIS IN STEEL FABRICATION OPERATIONS

The process analysis within steel fabricators indicates that inefficiencies are primarily caused by a lack of information, resulting in considerable time spent on inquiries to compensate for this deficiency. This analysis aimed to explore potential improvements for specific tasks to address information shortages, with a focus on the application of front-loading as a strategy. Despite the capabilities of dedicated steel CAD for creating both fabrication drawings and fabrication detail drawings, it has been observed that generic CAD software is frequently used for creating fabrication detail drawings, as shown in Figure 1 [12]. Responses from the survey highlighted a desire to enhance efficiency through seamless integration from detailed drawings to fabrication detail drawings, with the need for revisions due to design changes just before fabrication being identified as a key factor.

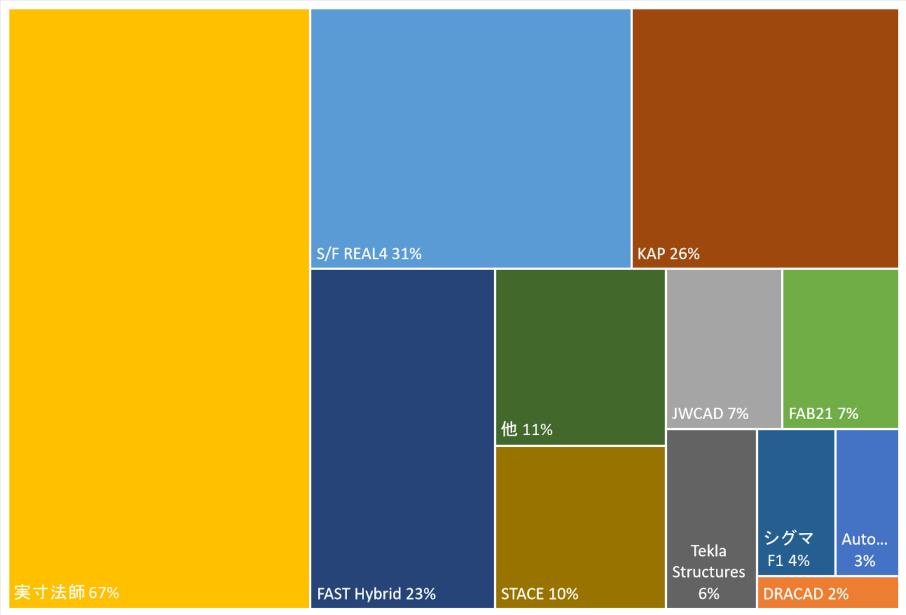

Figure 1. Main CAD Used for Fabrication Detail Drawings

Currently, many specialized steel CAD systems do not support simultaneous editing by multiple users. Therefore, for the task of creating fabrication detail drawings, work is often divided among several individuals and completed using generic CAD due to drawing schedule constraints. Once initiated in generic CAD, the workflow loses integration with specialized steel CAD, making it impossible to incorporate revisions, thus necessitating those subsequent tasks also be completed using generic CAD. This issue arises not only in the creation of fabrication detail drawings but also during the detailed drawing phase, leading to reduced efficiency in the creation of fabrication drawings. Therefore, implementing collaborative features in specialized steel CAD or establishing a seamless relationship between specialized steel CAD and generic CAD could be effective strategies for enhancing the efficiency of fabrication drawing creation. Meanwhile, in the current software environment, focusing on improving the efficiency of generating general drawings and reference drawings is seen as a practical solution.

A noted lack of information for general drawings and reference drawings indicates that front-loading could be a viable approach to increase the level of design detail. Front-loading should involve engineering considerations for constructability and manufacturability to minimize the need for inquiries and responses during the fabrication drawing creation stage. This engineering is commonly referred to as "fitting studies," the outcomes of which are incorporated into the fabrication drawings. This approach is also documented as "Summary of Inquiry Items" in the example of the steel product quality assurance system diagram in Figure 2.5.2 of literature [1]. "Fitting studies" can be conducted independently of the software environment, whether it be specialized steel CAD or generic CAD. Although there are few examples in Japan of engineering being carried out under a separate contract [11], finalizing details early can reduce the need for design changes in the fabrication drawing and fabrication detail drawing tasks, potentially increasing the efficiency of steel fabricators.

6. DISCUSSION

For steel fabricators, "fitting studies" can be divided into several categories, ranging from those relevant solely to the fabricators, such as manufacturability, to those requiring coordination not only with structural designers but also with architectural designers, like facades. For example, aspects like the shape and orientation of weld bevels, which relate to welding machinery, are specific to steel fabricators. This means such details are determined at the point the steel fabricator is decided, making them challenging subjects for front-loading. The direction of tucking in gusset plates for smaller beams, which is dependent on the position of the beams and thus involves constructability, requires coordination with general contractors, making it difficult to finalize during the design phase and less likely to be included in front-loading. However, details such as the reinforcement steel for elevators, which cannot be finalized until the supplier's specifications are determined, could potentially be front-loaded if decided during the design phase. Nevertheless, if suppliers are confirmed after contracts with general contractors are made, front-loading becomes challenging. Conversely, deficiencies in the level of detail in design, including architectural, structural, and mechanical aspects, are deemed suitable for front-loading.

Summarizing, "fitting studies" can be broadly categorized into four groups: 1) those related to design, 2) those related to design but primarily involving suppliers, 3) those related to construction, and 4) those related to fabrication. Front-loading is feasible for items related to design and, in some instances, for items that involve suppliers.

Moreover, steel fabricators are employing specialized steel CAD for creating fabrication drawings. However, the situation involves referencing CAD drawings for special specifications and reference drawings, and manually inputting this information. It is anticipated that further efficiencies could be achieved in the future by enabling the integration with specialized steel CAD as metadata through BIM, suggesting a pathway towards greater optimization.

7. SUMMARY

Steel fabricators dedicate a substantial amount of time to producing fabrication drawings, largely due to the ongoing exchanges of inquiries and responses right up until fabrication commences. Minimizing these inquiries through "fitting studies" by employing front-loading could prove to be an effective strategy for boosting efficiency in steel fabrication. Such "fitting studies" vary, including those that can be readily addressed through front-loading, primarily involving discussions with designers, and those that necessitate coordination with contractors or suppliers, making front-loading during the design phase more complex. Furthermore, certain details, such as the specifications for weld bevels related to welding equipment, are specific to steel fabricators and are determined at the point of selecting a fabricator, thus not typically suitable for front-loading. On the contrary, increasing the detail level early in the design phase, encompassing architectural, structural, and mechanical aspects, could result in efficiency gains.

At present, steel fabricators engage in contracts with general contractors without establishing design-phase agreements. Facilitating front-loading in steel engineering necessitates agreements during the design stage, requiring a distinction from current contracts to guarantee the independence of engineering efforts. Independent engineering, which involves considerations of constructability and manufacturability, indicates that contracted companies might be capable of generating fabrication drawings. This suggests that, in the future, it might be possible to supply general and reference drawings, with survey outcomes hinting at the feasibility of also delivering detailed drawings.

The application of specialized steel CAD to enhance the detail level during the design phase suggests that part of the approval process for necessary fabrication drawings could transition from traditional drawings to model approvals, thereby eliminating some drafting tasks and improving efficiency. However, precise criteria and processes for model approval remain undeveloped, pointing to the need for further discussions on the specifics of design and construction approvals. This area demands attention for advancing efficiency in steel fabrication operations. Currently, while steel fabricators handle engineering in-house, the assistance from independent specialized engineering firms could bring advanced knowledge and technology to the fabrication process, potentially offering a solution to the looming issue of a decline in skilled drafters due to aging. Additionally, for smaller steel fabricators, the heavy burden of drafting indicates that the provision of fabrication drawings by independent engineering firms could enable a more concentrated effort on specialized engineering tasks. This study’s investigation into front-loading techniques and their implementation hopes to restructure Japan's steel fabrication process and aid in enhancing productivity.

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NOTES

*1 General Drawings: Depicts the structure of a building, including its foundation, each floor, and each facade, showing the framework of columns and beams. This clarifies the relationship and arrangement of each structural member, serving as the basis for the creation of detailed drawings [1].
*2 Reference Drawings: Drawings that consolidate content that would become too complex if described individually in detailed drawings, or common content, including categorization and illustration of types and arrangements of bolts in high-strength bolted joints, shapes of welded joints, and details and layouts of temporary structures, facilities, and interior/exterior finishing members required for construction on site [1].
*3 Detailed Drawings: Illustrate the detailed shapes, dimensions, and arrangements of members attached to each steel product, divided according to the construction site assembly units [1].
*4 Specialized Steel CAD: CAD software specialized for steel fabrication that allows for the input of specifications and standard drawings in advance, enabling the addition of information such as plates, bolts, and welding when entering members like columns and beams. Also capable of calculating quantities and automatically drafting fabrication drawings.
*5 Special Specifications: Specifies project-specific and common specifications in contrast to the standard specifications commonly used by companies, primarily expressed in text and currently created in 2D CAD, not as metadata.
*6 Integrated Structural Calculation Software: Software commonly used in structural design to verify structural safety through frame analysis in accordance with Japanese laws and standards, capable of producing structural calculation reports.

REFERENCES

[1] Architectural Institute of Japan, “Technical Recommendations for Steel Construction for Buildings, Part1 Guide to Steel-rib Fabrications”, 2018.
[2] M. Urae et al., “Product Design of Building Steel Members during Fabrication Stage Incomplete and Alternation-prone Nature of Design/Specifications”, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, F, pp. 1031-1034, 1994.
[3] H. Kanisawa et al., “Actual processes of production design during the stage of steel component fabrication”, Journal of 10th Symposium on Building Production and Management Technology, Architectural Institute of Japan, pp. 207-212, 1994.
[4] Japan Federation of Construction Contractors, “Front Loading Guide 2019”, 2019
[5] Japan Federation of Construction Contractors, “Request to All Private Businesses and Clients Who Order Construction Work”, 2023.
[6] H. Kanisawa et al., “The State-of-the-art of Production Design Practice of Steel Fabricators”, Journal of 11th Symposium on Building Production and Management Technology, Architectural Institute of Japan, pp111-118, 1995
[7] A. Umekuni and N. Goto, “A Study on the Division of Labor in Steel Fabrication”, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, F-1, pp1287-1288, 2010
[8] J. Kim et al., “Study on Rationalization of Steel Frame Production in Building Projects, Part 1, Overview of the Study and Analysis of the Steel Frame Fabrication Process”, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, F-1, pp1283-1284, 2010
[9] J. Kim et al., “Study on Rationalization of Steel Frame Production in Building Projects, Part 2, Work on Design Modification of Steel Fabricators”, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, F-1, pp1287-1288, 2011
[10] J. Kim et al., “ANALYSIS OF DESIGN CHANGE ORDERS FOR STRUCTURAL STEEL CONSTRUCTION AND FABRICATOR’S METHOD OF RESPONSE”, Proceedings of 27th Symposium on Building Construction and Management of Projects, pp213-218, 2011
[11] J. Okohsi, K. Shide, “RESEARCH ON CONTRACTS AND ENGINEERING IN STEEL FABRICATOR”, Journal of Architecture and Planning, Architectural Institute of Japan, Vol. 88, No. 814, pp. 3353-3363, 2023.
[12] J. Okoshi, “Future Information Collaboration in The Field of Architectural Steel Frames, BIM Collaboration with Steel Fabricators Questionnaire Discussion and Issues”, Steel Structure Technology, Japan Steel Structure Journal, Vol.32, No.379, pp34-37, 2019