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Comparison of OSC (Off-Site Construction) Level Measurement Methods

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Abstract: Studies have shown that the implementation of OSC (off-site construction) is beneficial. However, most studies have relied on simulated project data to forecast the potential advantages of OSC, often using surveys or expert consultations as their primary research methods. Others have based their analyses on a specific sample size, focusing on cost savings and reduced construction time. Such approaches inherently possess limitations. In this study, we define "OSC level measurement" as the comprehensive process of quantifying the application of OSC elements throughout the project lifecycle. Numerous studies have proposed methods for OSC level measurements. However, they vary in their applicability to different facility types and project phases and employ country-specific quantification items and methods. These variations complicate the comparison or integration of OSC measurement methods on an international scale. The comprehensiveness of the representations in the existing industry foundation classes (IFCs), which is required to carry out automated OSC level measurement, is not yet investigated. This study aimed to systematically compare and analyze various methods for measuring OSC levels in construction projects. We intend to provide researchers and professionals with the necessary characteristics and requirements to develop standardized OSC level measurement methods in the future. The key takeaways emphasize the need for establishing the necessary standardization of the list of OSC elements, creating a framework for standardized quantification items using IFC elements based on BIM data to measure the extent of OSC elements' application, and unifying the quantification methods for assessing the proportion of OSC elements. Ultimately, this standardization will pave the way for more informed decision making, innovation, and the implementation of sustainable solutions in the construction industry.

Keywords: OSC level measurement; OSC element; IFC element; BIM

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1. Introduction

In recent years, off-site construction (OSC) has gained prominence as a preferred construction method in various countries. It is widely recognized as a solution to numerous challenges that traditional on-site construction faces—low productivity, inadequate logistics management, safety hazards, environmental pollution, waste generation, and quality issues [1–5]. Although research on OSC has been on the rise (Jin et al., 2018) [6], with many studies confirming its practical application [2,7–11], these studies have predominantly focused on the necessity of implementing OSC and its resulting application effects. In particular, the application effects suggested by these studies are broadly categorized into direct and indirect impacts. Direct effects emphasize reductions in on-site work, a decreased reliance on skilled labor, increased productivity due to enhanced work efficiency resulting from reduced on-site tasks, cost savings in waste disposal, material damage, and overall expenses through expedited material procurement, as well as the potential for simplified construction processes and systematic on-site management. Indirect effects highlight the environmental benefits such as reduced water, dust, and noise pollution, as well as energy savings resulting from decreased material wastage. Moreover, they propose improvements in worker safety by reducing exposure to adverse weather conditions, heatwaves, and hazardous working environments. However, these studies face significant limitations in presenting practical OSC application effects due to challenges in utilizing objective and reliable measurement indicators and procedures.

Many of these studies rely on simulated project data or use surveys and expert opinions to predict the expected outcomes of OSC implementation. They also frequently assess the possible impacts, such as cost and emission reductions, based on a small number of completed projects [3,8–13]. In this study, OSC level measurement refers to the systematic planning and quantification of OSC elements—be it systems, methods, or components—from the initial phases of design through to construction. Higher levels of OSC implementation are presumed to lead to improved operational productivity, reduced labor input, cost savings, shorter construction durations, better quality, enhanced worker safety, and technological innovation.

Recent studies have delved into the concept of measuring OSC levels, with various governments and research bodies contributing to the discourse [5,8,11,14–24]. However, these methodologies differ in their applicability to various facility types and project phases and often employ country-specific evaluation criteria and quantification methods. This inconsistency has made it difficult to compare or integrate OSC measurement methods on an international scale. Unfortunately, comprehensive research that could guide the development of standardized OSC level measurement frameworks is still lacking. In addition, the automated process based on industry foundation classes (IFCs), which is a global standard of building information modeling (BIM), is required to enable the OSC level measurements in a timely and internationally consistent manner. However, the representations included in the existing IFCs are not yet investigated, hindering our understanding of their comprehensiveness for international comparison.

The aim of this study was to fill this research gap by systematically comparing and analyzing various methods for OSC measurement. Additionally, this study explored the comprehensiveness of the existing IFCs for timely OCS level measurement potential. Based on them, we intend to provide the essential characteristics and requirements necessary for developing standardized approaches to OSC level measurement in construction projects.

2. Research Methodology

In this study, we performed an in-depth comparative analysis of various methods for measuring OSC levels. Our criteria for comparison were identified through interviews with 12 experts, each boasting over 15 years of experience in construction and involvement in at least three OSC projects. We described each method in the context of its background and objectives for measurement. This study also systematically examined the application of these methods across different types of facilities and various project phases, including conceptual planning, basic design, detailed design, and construction planning. Evaluation components were categorized based on criteria such as work breakdown structure (WBS), element breakdown structure (EBS), and other pertinent factors. To delve into the quantification of OSC levels, we scrutinized the use of weighted assessments, the quantification of individual OSC elements, and the units of measurement. We also looked into the practical application of indices such as the labor-saving index.

The findings from this comparative analysis were thoroughly vetted through follow-up interviews with eight of the experts involved in the initial item selection. This iterative review process was designed to provide researchers and professionals with valuable insights into the essential characteristics and requirements needed for the future development of standardized methods for measuring OSC levels. In addition, since IFCs are needed for timely and internationally consistent measurements, the existing IFC has been investigated to understand what additional representations are required for such measurements (refer to Figure 1).

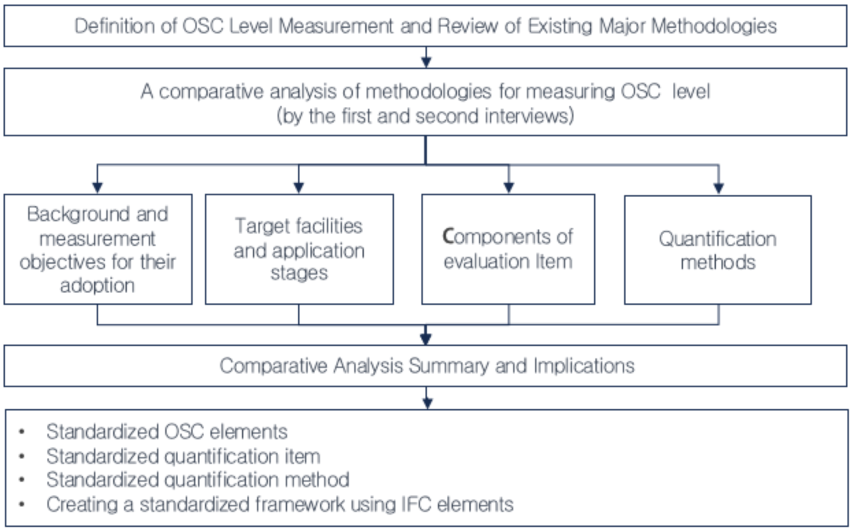

Figure 1. Research procedure and method.

3. Preliminary Review

Research Trends in OSC Level Measurement Methodologies

To date, various studies concerning OSC measurements have been conducted, as detailed in Table 1. These studies fall into two broad categories: national-level and individual-level research.

Table 1. Methodologies for measuring OSC levels.

Methodologies	Metrics	Source
Modern method for construction (MMC)	Premanufactured value (PMV)	[5,24]
Buildability	B-score and C-score	[23,24]
Building estimating system (BES)	BES-score	[22]
IBS	IBS-score	[16]
Prefabrication ratio (P-ratio)	Prefabrication ratio (P-ratio)	[21]
Off-site work done ratio value	Off-site work done ratio	[14]
Off-site production components ratio	Number of off-site production components	[8]
Energy consumption saving by prefabrication	Prefabrication's energy-saving ratio	[15]
Analytical framework for optimal level of prefabrication	Measuring the level of prefabrication	[11]
Index hybrid (CIH) approach	Prefabrication volume ratio	[19]
Constructability assessment model	Constructability score	[20]
Mathematical framework to measure product modularity	Measuring product modularity	[18]
Determining the level of prefabricated modules	Ranking of top most critical factors	[17]

On the national front, the UK government [5] launched a research project in 2019 to assess advancements in construction methods, emphasizing the importance of premanufactured value (PMV) as a key metric for evaluating the modern method of construction (MMC). The Singapore government [23] advocates design techniques that minimize on-site labor, utilizing metrics like the buildable design score (B-score) and constructability score (C-score) to promote the use of advanced technologies and innovative products during construction. Similarly, since 2017, the Hong Kong government [22] has employed a building estimating system (BES) to gauge design simplification, aiming to reduce costs and boost construction efficiency. The Malaysian government [16] has evaluated industrialization in construction using the industrialized building system (IBS). In 2017, the Chinese government [21] introduced the prefabrication ratio (P-ratio) to measure the use of premanufactured components, aiming to streamline on-site work and accelerate housing projects. This is a crucial strategy for quickly delivering a large volume of housing units. Individual research efforts have also contributed various metrics and methods. For instance, Alinaitwe et al. [14] assessed the off-site work ratio, while Hong et al. [8] introduced a method for counting off-site prefabricated components.

Zhu et al. [15] examined the energy-saving ratio to evaluate OSC's environmental impact, and Weisheng et al. [11,19] proposed frameworks and metrics for measuring optimal OSC levels. Additionally, they employed the constructability assessment model [20] to evaluate constructability. Shamsuzzoha et al. [18] developed a mathematical framework for product modularity assessment, and Seidu et al. [17] identified key factors for ranking off-site modularization levels.

In this study, we primarily focus on five national-level OSC measurement methodologies: Singapore's Buildability, the UK's MMC, Hong Kong's BES, Malaysia's IBS, and China's P-ratio. Our selection is motivated by the systematic management processes that these five methodologies offer for continuous OSC level measurement.

In this study, five methods have been selected, and their selection is based on several reasons. Firstly, these methods are widely used in the current construction industry and are internationally recognized methodologies. This is because these methods are applicable to various project types and industrial sectors, and they have demonstrated empirical cases and effective performance. The reason for excluding various other methods is to select the methods that best fit the purpose and research questions of the study. Considering the scope and objectives of the research, it was judged that these five methods are the most suitable, and they have been confirmed to be widely used in major countries or regions. Additionally, they provide robust data collection and verification capabilities, making them conducive for a comparative analysis of OSC level measurement approaches.

4. Comparative Analysis of OSC Level Measurement Methodologies

The five methodologies under consideration—Buildability, PMV, BES, IBS, and P-ratio—each offer unique approaches for quantitatively measuring OSC levels in construction projects. This study conducts an in-depth comparative analysis of these methods, focusing on three key dimensions: (1) the historical background and objectives behind their development, (2) their applicability to various types of facilities and phases of construction, and (3) the specific items and techniques used for quantification. These areas of inquiry were formulated through interviews with 12 seasoned experts, each having over 15 years of experience in the construction industry and involvement in at least 3 OSC projects, as shown in Table 2.

Table 2. Descriptive information of interviewers.

Measure	Item	Frequency
Role	Owner	1
	Designer	3
	Manufacturer	2
	Contractor	6
Education	High diploma/associate degree	1
	Bachelor	6
	Master or above	5
Experience in construction	5–10 years	
	10–15 years	
	15–20 years	8
	25–30 years	4
Experience in off-site construction	1–2 years	
	3–4 years	7
	5–9 years	5

4.1. Background and Measurement Objectives for Their Adoption

4.1.1. Buildability

In Singapore, the Buildability methodology is widely acknowledged as a leading metric in the realm of OSC measurement. Originating in the 1990s, during a period of rapid economic growth and increasing dependence on foreign construction labor, the methodology became even more pertinent in the early 2000s. The societal concern over foreign labor reliance in the construction sector led to the enactment of the Building Control Act in 2001, which formally introduced the Buildability framework. Within this context, Buildability assessments utilize two central metrics: the B-score and the C-score. Each of these scores is evaluated on a scale that goes up to 120 points.

The B-score measures the extent to which prefabricated components are incorporated during the design phase to reduce on-site labor requirements. Conversely, the C-score evaluates the effectiveness of construction techniques and methods in minimizing on-site labor during the construction phase. At present, Singapore employs the B-score and C-score indices to gauge the extent of OSC implementation in individual projects, while also maintaining a continuous measurement of industry-wide OSC adoption levels.

4.1.2. PMV

The modern method of construction (MMC) in the United Kingdom was initially popularized through the "Farmer Review" in 2016. This landmark report advocated the adoption of the MMC as a solution to the growing challenges of labor shortages and declining productivity in the construction sector, particularly in the post-Brexit landscape. The UK government subsequently endorsed the MMC's potential, devised a technological implementation roadmap, and launched the MMC Framework in 2019. In 2020, "The Construction Playbook" was published to provide policy guidelines for the MMC, and a series of validation initiatives were rolled out in 2021, focusing primarily on housing supply projects. Within the MMC Framework, the PMV metric is employed to measure OSC levels. The PMV quantifies the proportion of the total construction cost attributed to premanufactured components, expressed as a percentage. An uptick in the PMV value indicates potential gains in on-site construction productivity due to less reliance on labor. The UK government is currently examining the broader economic implications of the PMV through pilot site implementations within its domestic construction industry.

4.1.3. BES

By 2017, Hong Kong's construction costs had soared, ranking as the highest in Asia and second only to New York on a global scale [25]. To address this, the Hong Kong government introduced the BES. Aimed at standardizing construction designs through OSC technology, this methodology also seeks to refine the construction process via prefabricated components and the mechanization of construction techniques. The BES system consists of 5 modules, incorporating a total of 209 design considerations. This method utilizes the BES-score as its primary metric, featuring a total of 1000 points, including an additional 200 bonus points. Specific project tasks in each construction phase are outlined in the BES guidelines, and the government mandates the submission of BES-score calculations. Additionally, a specialized tool was developed to monitor the continual adoption of OSC methodologies in Hong Kong's construction projects.

4.1.4. IBS

The Malaysian government initiated the first phase of its IBS development roadmap between 2005 and 2010, taking cues from Singapore's Buildability methodology. Active formulation of the IBS methodology began in 2015, with the aim of leveraging OSC technology to boost productivity and modernize construction techniques in building projects. The system's performance is gauged using an IBS-score, scored on a scale from 0 to 100 points. For public construction projects exceeding MYR 10 million, submitting an IBS-score remains optional, yet a minimum score of 70 is required. For private construction projects valued over MYR 50 million, a minimum IBS-score of 50 is mandated. To further elevate construction standards, the Malaysian government is in the process of revising regulations to raise the required minimum IBS-score for both public and private construction projects.

4.1.5. P-Ratio

After privatizing housing in 1998 and dissolving the welfare-oriented housing allocation system, China experienced a surge in rural-to-urban migration. This led to escalating urban housing prices and acute housing challenges in major cities. In response, the Chinese government introduced assembly building standards in 2018, aiming to advance prefabricated building technology as part of a broader poverty alleviation strategy through housing stability. Under its Twelfth Five-Year Plan for the construction industry, the government is committed to actively nurturing the prefabricated construction sector. This study marks the first introduction of a prefabrication ratio (P-ratio) methodology. The P-ratio quantifies the extent of standardized design and the use of premade components, expressed as a percentage. To spur ongoing improvements in prefabrication, the Chinese government has graded P-ratio levels into A, AA, and AAA categories. Incentives such as tax benefits, financial grants, and increased floor area ratios are offered to stimulate the uptake of prefabricated building techniques.

4.2. Background and Measurement Objectives for Their Adoption

The comparative analysis of facilities subject to five different OSC measurement methodologies—namely, Buildability, PMV, BES, IBS, and P-ratio—is summarized in Table 3. Buildability, the BES, and the IBS have broad applicability, covering almost all facility types, except power plants and waste treatment plants. The PMV, on the other hand, is chiefly used in residential and commercial structures, but it also extends to industrial facilities. The P-ratio is mainly used for prefabricated residential and commercial buildings.

Table 3. Comparison of type of applicable facilities.

Division	Residential Facility	Commercial Building	Industrial Building	Educational Facility	Medical Facility	Cultural Facility	Plant Facility
Buildability	✓	✓	✓	✓	✓	✓	
PMV	✓	✓	✓				
BES	✓	✓	✓	✓	✓	✓	
IBS	✓	✓	✓	✓	✓	✓	
P-ratio	✓	✓					

The relevant project phases for these different OSC measurement methods are detailed in Table 4. The PMV is versatile, applicable from the planning to the construction phases. Buildability, the BES, and the IBS are more restricted, applying to basic, detailed, and construction phases only. The P-ratio is limited to the detailed design and construction phases.

Table 4. Comparison of applicable project phase.

Division	Conceptual Design	Basic Design	Detailed Design	Construction
Buildability		✓	✓	✓
PMV	✓	✓	✓	✓
BES		✓	✓	✓
IBS		✓	✓	✓nd can be r
P-ratio			✓	✓

4.3. Quantification Item and Methods

4.3.1. Buildability

Buildability's assessment framework incorporates five key elements based on the work breakdown structure (WBS): structure, architecture, mechanical systems, electronics, and plumbing. During the design phase, these elements are divided into three broader categories: structure and architectural systems, MEP systems, and an additional category for innovation and other special considerations. For the construction phase, categories shift to structure and AMEP systems, with an extra slot for adherence to good industry practice (refer to Figure 2).

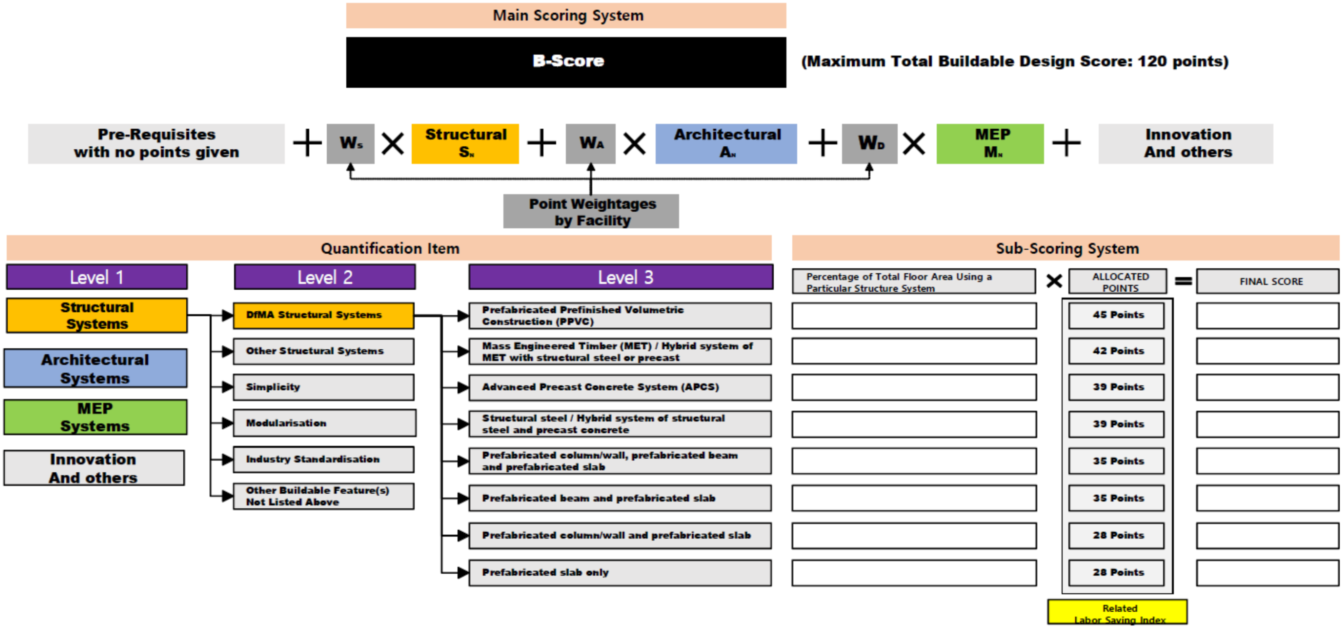

Figure 2. A schematic diagram of the quantification item and method for the B-Score.

The B-score quantification method assigns varying weights depending on the facility type. For each specific criterion, the assigned score based on OSC technology alternatives is multiplied by the ratio of prefabricated components used, be it in terms of floor area, length, or other units. Scores are then summed up, and it is worth noting that higher scores are directly correlated with labor efficiency, as indicated by the labor-saving index. Continuously measuring buildability is instrumental in monitoring improvements in construction productivity resulting from labor savings. Conversely, the C-score quantification does not discriminate based on facility type. It is calculated as the sum of three components: structural systems (up to 60 points), AMEP (up to 45 points), and good industry practices (up to 15 points). The method for assessing these scores is in line with that used for the B-score. However, in evaluating the good industry practices' component, the focus is not on the proportion of the area applied but rather on the quantity or presence/absence of specific implementations (refer to Figure 3).

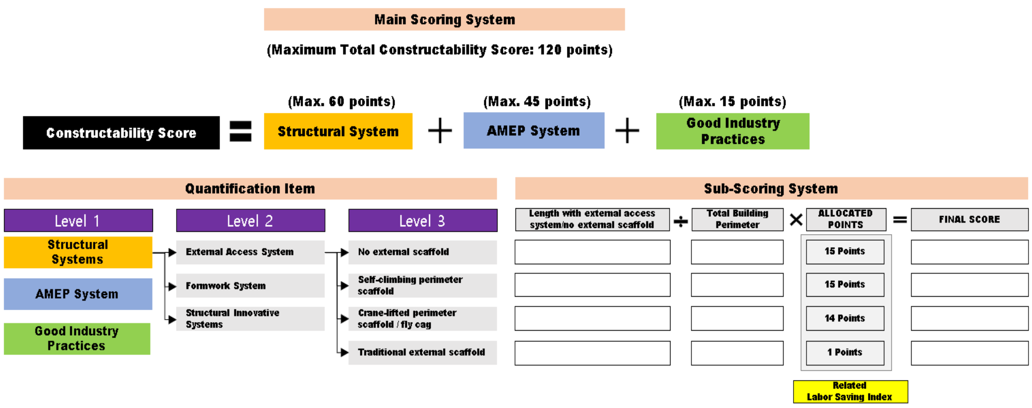

Figure 3. A schematic diagram of the quantification item and method C-Score.

4.3.2. PMV

The PMV's quantification is rooted in the EBS, allowing for a granular evaluation of specific processes and areas within a project. This methodology aligns well with the NRM system employed in the UK, establishing it as a particularly effective approach. It serves as a vital tool for decision making, aiding in determining the degree of OSC implementation throughout the entire project lifecycle, from planning to construction. When it comes to quantification, the PMV methodology does not assign weights based on facility type, process, or area. Instead, it standardizes the assessment by focusing solely on the proportion of costs associated with prefabricated components (refer to Figure 4).

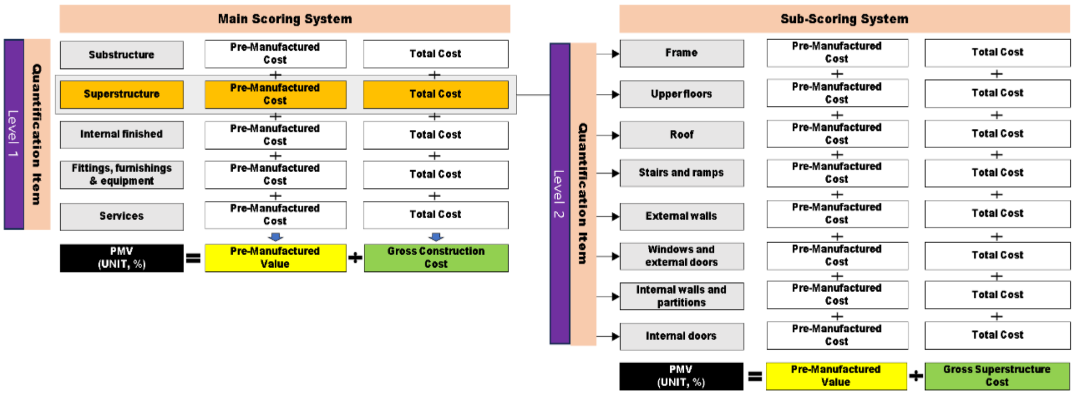

Figure 4. A schematic diagram of the quantification item and method for PMV.

4.3.3. BES

For the BES, the primary structure is organized into five modules, each targeting different aspects of business processes. Module 3, in particular, emphasizes measuring the extent to which OSC elements are applied. In the quantification process, the points allocated to the top five modules are summed, with modules 1 to 4 contributing a total of 1000 points and module 5 offering an additional 200 bonus points. Within each module, the quantification method assigns points based on the area or length where OSC-related components are used, categorized into various technical segments. When a quantitative assessment of the application ratio proves challenging, expert judgments are sought to determine the presence or absence of a particular application. These assessments are then converted into numerical values and incorporated into the total score (refer to Figure 5).

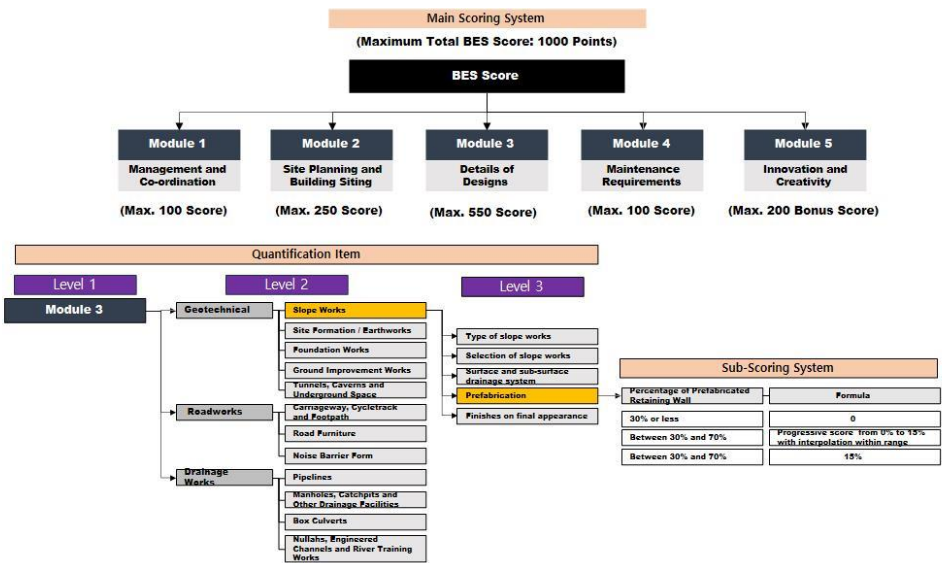

Figure 5. A schematic diagram of the quantification item and method for BES.

4.3.4. IBS

In IBS quantification, the focus is primarily on two design components: structural systems and wall systems. An additional category, "Innovation and Others", is considered during the construction phase. This methodology could be viewed as a streamlined version of the Buildability assessment framework. Unlike methods that assign weights based on facility types, the IBS-score calculates each specific quantification item by multiplying the proportion of applied prefabricated components by either the floor area or length for each OSC-related technology alternative. This results in an aggregate score. The term "IBS factor" mirrors the concept of the allocation score used in Buildability's B-score, quantifying labor savings for each alternative in numerical terms (refer to Figure 6).

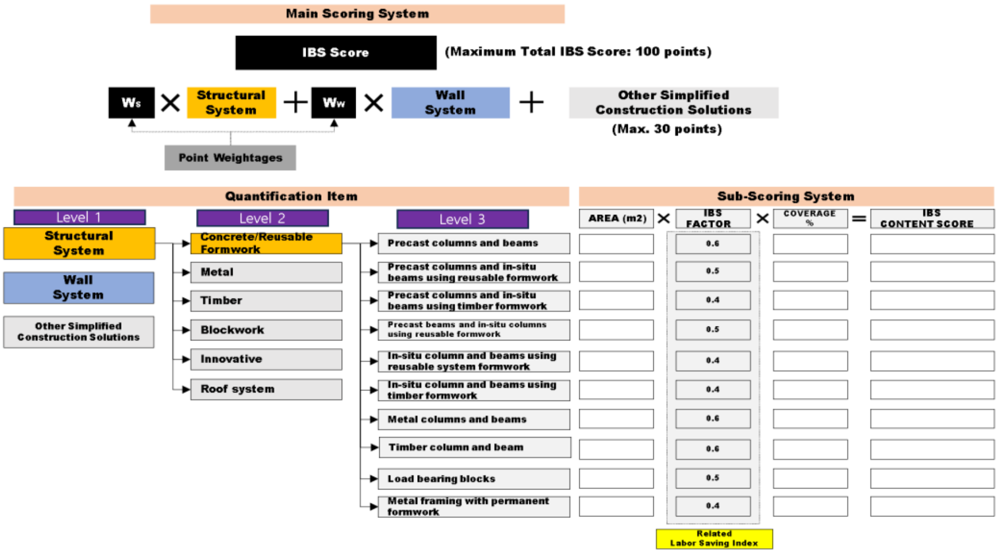

Figure 6. A schematic diagram of the quantification item and method for IBS.

4.3.5. P-Ratio

For the P-ratio, quantification involves three primary components: structural and wall systems, along with supplementary systems like interiors, bathrooms, kitchens, and pipelines. Unlike other methods, this one does not account for innovative construction techniques aimed at enhancing on-site productivity. As for the quantification methodology, there are no weighting factors which are applied based on the type of facility or specific evaluation criteria. Rather, the scoring is based on the proportion of prefabricated components applied, scaled to various OSC technologies, such as volume, area, or length. Differential scores are given based on how well these components meet the criteria in various categories, with minimum benchmarks established for structural and wall systems (refer to Figure 7).

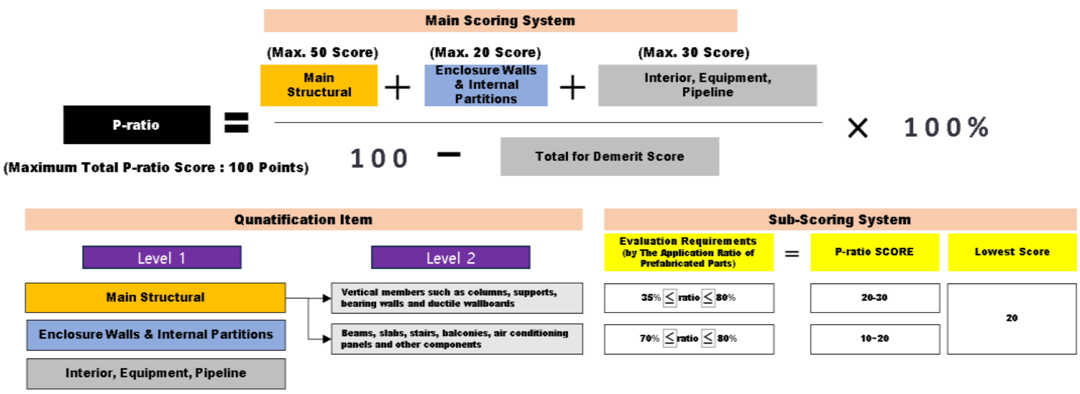

Figure 7. A schematic diagram of the quantification item and method for P-ratio.

5. Comparative Analysis Summary and Implications

This study aims to delineate the features and prerequisites for crafting a standardized approach to measure OSC levels. To achieve this, we conducted secondary interviews with eight experts who contributed to the selection of the items for comparative analysis, with their information shown in Table 5.

Table 5. Descriptive information of second interviewers.

Measure	Item	Frequency
Role	Owner	1
	Designer	2
	Manufacturer	2
	Contractor	3
Education	High diploma/associate degree	1
	Bachelor	3
	Master or above	4
Experience in construction	5–10 years	
	10–15 years	
	15–20 years	6
	25–30 years	2
Experience in off-site construction	1–2 years	
	3–4 years	3
	5–9 years	5

5.1. Standardized OSC Elements

The existing methodologies for measuring OSC—Buildability, PMV, BES, IBS, and P-ratio—all aim to reduce on-site work by maximizing the use of prefabricated components. Despite this common objective, these methodologies vary significantly in their definitions and scopes, specifically in how they measure the reduction in on-site work. To develop a universally applicable, standardized methodology for OSC measurement, it is crucial to establish a comprehensive list of predefined systems, methods, and components with standardized OSC attributes. This list should be applicable across all project phases, including conceptual planning, design, and construction.

5.2. Standardized Quantification Item

Table 6 reveals considerable variations in the composition of quantification items among the current OSC measurement methodologies. For instance, Buildability takes a multi-faceted approach, considering structural, architectural, mechanical, electronic, and plumbing components. It also includes considerations for innovation, assessing technologies that could reduce labor requirements by at least 20% compared to conventional methods. From a construction standpoint, Buildability evaluates the adoption of good industry practices, focusing on enhanced on-site coordination and optimized planning and material usage to boost efficiency. Conversely, the PMV employs an EBS, evaluating various building aspects like the substructure, superstructure, and internal finishes. It also considers innovative technologies and equipment aimed at labor reduction and productivity enhancement, guided by the MMC Framework, Categories 6 and 7. The BES, on the other hand, uses a civil work WBS, incorporating categories such as geotechnical and marine work for evaluation. However, its treatment of mechanical, electronic, and plumbing components within the OSC framework remains relatively underdeveloped.

The IBS and the P-ratio predominantly focus on the wall system components within the WBS, largely because of their substantial influence on OSC techniques such as prefabricated prefinished volumetric construction (PPVC), mass-engineered timber (MET), and precast concrete. Notably, these techniques, such as dry-wall applications, contribute to significant cost savings in construction. The IBS further extends its scope to include “other simplified construction solutions", which evaluates the application of repetitive layouts and innovative construction methods during the construction phase.

Table 6. Comparative analysis of quantification item structure.

Quantification Item Structure		Buildability	PMV	BES	IBS	P-Ratio
Work Breakdown Structure (Building work)	Structure	✓			✓	✓
	Architecture	✓			✓	✓
	Mechanical	✓				
	Electronic	✓				
	Plumbing	✓				
Element Breakdown Structure (Building work)	Substructure		✓			
	Superstructure		✓			
	Internal finished fittings		✓			
	and furnishings and equipment		✓			
	Services					
Work Breakdown Structure (Civil work)	Geotechnical			✓		
	Roadworks			✓		
	Drainage Works			✓		
	Water Works			✓		
	Marine Works			✓		
	Elevated structures Works	✓		✓	✓	
	Facility structures	✓		✓	✓	
Others		✓	✓		✓	
Example of Analysis		Figures 2 and 3	Figure 4	Figure 5	Figure 6	Figure 7

Initial research is essential for developing a standardized framework that allows for international comparisons, and which can accommodate future quantification items and other considerations. For instance, a comparative framework based on the international framework for the classification of industry foundation classes (IFCs) could be effective. This approach would enable the measurement and comparison of specific systems, construction methods, and materials in the context of OSC, even before the establishment of standardized quantification items.

5.3. Standardized Quantification Method

As highlighted in Table 7, there are pronounced differences in the current methods for quantifying OSC. For example, Buildability incorporates weightings for both facility types and individual quantification items, whereas the IBS only applies weightings to individual quantification items. In contrast, the PMV, the BES, and the P-ratio do not consider any weightings. Regarding the scoring system for individual items, Buildability, the BES, and the IBS use alternative scoring tables centered around OSC elements. Specifically, Buildability and the IBS calculate scores based on labor-saving efficiency, termed the IBS factor. To measure the proportion of OSC elements employed, Buildability and the IBS consider factors like floor area or length, while the BES and the P-ratio use metrics like area, length, or volume. The P-ratio's scoring system is unique in that it specifies quantification methods based on preset compliance benchmarks for OSC elements. The PMV, on the other hand, relies on the ratio of prefabricated component costs to total costs for its quantification. While the PMV and the P-ratio express quantification in percentages, Buildability, the BES, and the IBS use a point-based system.

In summary, for the development of a standardized approach to measure OSC levels, it is crucial to create a standardized method for quantifying the application of OSC elements. Such standardization could provide the foundational data necessary for creating a uniform system to measure OSC levels.

Table 7. Comparative analysis of quantification methods.

Division		Buildability	PMV	BES	IBS	P-ratio
Weighting		✓			✓	
Quantity of Work	Floor area	✓			✓	
	Area (m^2)	✓		✓	✓	✓
	Length of wall (m)	✓		✓	✓	✓
	Volume (m^3)			✓		✓
	Application (Yes/No)	✓		✓	✓	
Weight Scoring System	Scoring	✓		✓	✓	✓
	Costing		✓			
Quantified Unit	Percent (%)		✓			✓
	Point (Score)	✓		✓	✓	
Example of Analysis		Figures 2 and 3	Figure 4	Figure 5	Figure 6	Figure 7

5.4. Creating a Standardized Framework Using IFC Elements

It is essential to establish a standardized framework for international comparison of future quantification items and additional consideration factors. For instance, it is feasible to construct a comparative framework based on the IFC elements. The majority of quantification items commonly used for OSC level measurement in existing methodologies can be standardized at the IFC element level, as depicted in Figure 8. However, for elements such as Buildability's prefabricated bathroom unit (PBU) or prefabricated and prefinished wall with MEP services, their representation may require the addition of a new "Object Type" called "IFC OSC Assembly (tentative name)" to account for attribute values not defined in the existing IFC element "Object Type". Ayinla et al. (2020) [26] highlighted that the IFC4 group element lacks provisions for prefabricated systems like volumetric units (e.g., pods and room units) and complete building systems. While utilizing existing IFC shared building element properties is feasible, this study proposes a method to address the evolving nature of OSC elements by creating a new "OSC Assembly type" within the IFC element "Object Type". Furthermore, advanced research into the "OSC elements Library" associated with composite prefabricated components is necessary and should precede this endeavor.

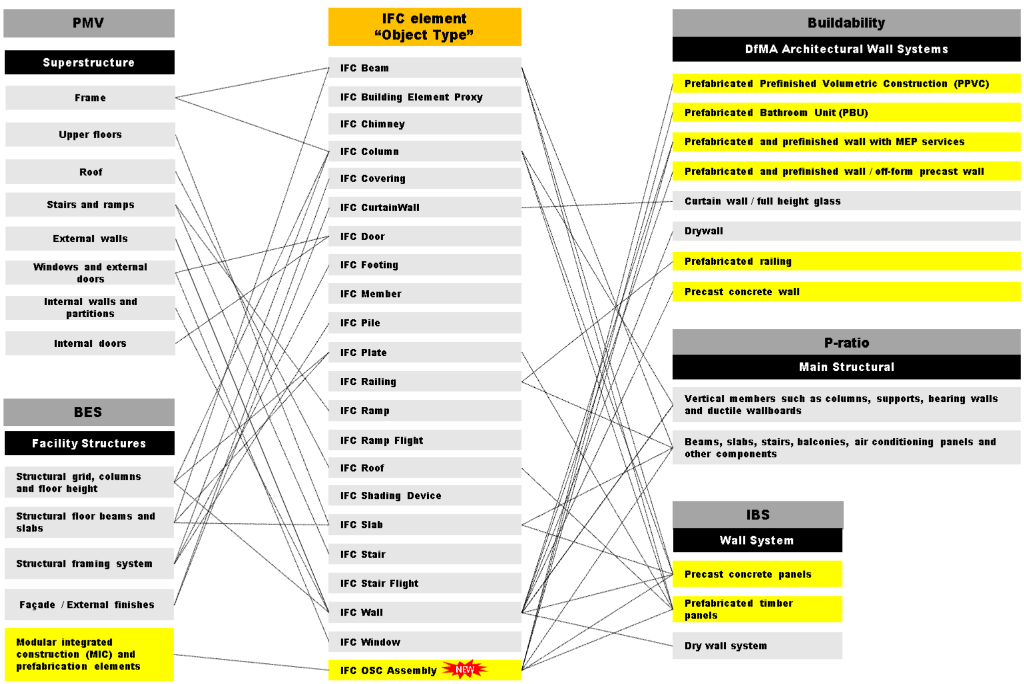

Figure 8. Examples of a standardized framework using IFC elements.

This approach enables the measurement and comparison of the degree of applicability of specific systems, construction methods, and materials related to OSC before establishing standardized quantification items and methods (refer to Figure 8).

6. Conclusions

This study scrutinizes the disparate approaches used by five methodologies—Buildability, PMV, BES, IBS, and P-ratio—to measure OSC levels. Notably, these methodologies diverge considerably in their quantification items. While Buildability adopts a WBS rooted in building construction, the BES employs a WBS with a civil engineering focus. Conversely, the IBS and the P-ratio center their quantification on structural and wall system components within the WBS. Each method also varies in its treatment of additional factors. Buildability integrates innovation from both design and construction perspectives. From a construction perspective, it integrates good industry practice as a key factor, evaluating the implementation of innovative construction technologies through the lens of on-site adjustments and the effectiveness collaboration efforts. The PMV, leveraging the MMC Framework Categories 6 and 7, includes items aimed at boosting productivity via innovative technologies. The IBS, listed under the category of "other simplified construction solutions", assesses the application level of innovative construction techniques during the construction phase.

The variations extend to the computation of quantification scores and units. Buildability and the IBS incorporate weighted scoring, while the PMV and the P-ratio express their metrics in percentages. To determine the application ratios of OSC elements, Buildability and the IBS consider metrics such as floor area, wall length, and area, whereas the BES and the P-ratio focus on area, wall length, and volume. Noteworthy is the integration of a labor-saving index by Buildability and the IBS in their quantification methodology.

The quantification of the PMV is rooted in cost analysis, enabling a comprehensive evaluation of specific processes and project segments. This methodology seamlessly aligns with the NRM system employed in the UK, establishing itself as a highly effective strategy. The PMV provides a simple and intuitive calculation process. Moreover, it enables the easy and intuitive calculation and confirmation of OSC level measurement results for each part and process. The system offers flexibility for future expansion and updates by various stakeholders. Additionally, serving as a crucial decision-making tool, the PMV assists in determining the level of OSC implementation across the project's lifecycle, from planning to construction. However, its application during the conceptual design phase is limited to establishing overarching target PMV values and a preliminary scope, based on insights from the analysis of similar cases. In other countries where the NRM system is not applied, its widespread use is restricted.

These divergences present a complex landscape that hinders easy comparison or integration of OSC measurement methodologies on a global scale. Therefore, this study proposes a method to address the evolving nature of OSC elements by creating a new "OSC Assembly type" within the IFC element "Object Type". Furthermore, advanced research into the "OSC elements Library" associated with composite prefabricated components is necessary and should precede this endeavor. This approach enables the measurement and comparison of the degree of applicability of specific systems, construction methods, and materials related to OSC before establishing standardized quantification items and methods. Such concerted efforts are expected to lay the groundwork for more advanced discussions on the standardization of OSC measurements, potentially tailored to specific facility types and project phases. Also, the standardized OSC measurement methodologies will not only streamline comparisons but also contribute significantly to advancing discussions on sustainable construction practices globally. Ultimately, this standardization will pave the way for more informed decision making, innovation, and the implementation of sustainable solutions in the construction industry.

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