Key Performance Indicators of Offsite Construction Supply Chains: A Review

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Abstract –

Offsite construction (OSC) has demonstrated various benefits, but its wide adoption is constrained by complex and dynamic supply chains. It is vital to establish a comprehensive performance measurement system for OSC supply chains, which however has seldom been explored in detail. This paper aims to identify the key performance indicators (KPIs) of OSC supply chains through a systematic review of the literature published from December 2000 to March 2021. A total of 65 KPIs were extracted from 84 articles, including 35 economic, 19 social, and 11 environmental KPIs. A consistent KPI framework was initially proposed to describe how the KPIs jointly assess OSC supply chains. The results indicate that previous research mainly focused on the economic aspect of OSC supply chains while social and environmental performance were largely overlooked. Under each aspect, several indicators were ascertained as frequently cited KPIs, while some others received relatively little attention. This paper contributes to a better understanding of OSC supply chain performance by investigating current measurement efforts from a multidimensional perspective. To practically develop a quantifiable assessment method, further research should build on the framework and pay more attention to the overall or total performance and the neglected KPIs, particularly in social and environmental aspects.

Keywords –

Offsite Construction; Supply Chain; Key Performance Indicators; Performance Measurement

1 Introduction

Offsite construction (OSC) transfers onsite activities into a controlled manufacturing environment [1], with many benefits such as shortened construction time, improved productivity, better quality and enhanced sustainability [2]. However, a wider take-up of OSC is constrained by its complex and dynamic supply chains that feature complicated and interdependent processes, including design, manufacturing, transportation, storage, and assembly of building components, elements or modules [3, 4]. Regarding OSC, the lack of a comprehensive supply chain performance measurement could result in sceptical attitudes of stakeholders towards this innovative construction method without a clear vision of its superiority. Performance measurement for OSC supply chains is therefore growing important, which helps determine how successful organisations attain their objectives and highlight improvement opportunities [5].

Previous research proposed diverse performance metrics ranging from fundamental ones including cost, time and quality [6, 7] to more sophisticated ones including stakeholder satisfaction, technology transfer, partnering, and carbon emissions [8-10]. These studies focused on specific segments of OSC supply chains and partly evaluated the economic, social and environmental performance. However, fragmentation in using these indicators may not achieve satisfactory results, as different stakeholders often emphasise their individual performance rather than the whole supply chain. Scholars stressed the importance of simultaneously rather than separately considering the three pillars above to enhance OSC supply chain systematically [5, 11]. As such, there is an urgent need to develop a holistic framework based on KPIs to evaluate the overall performance efficiently.

This paper aims to identify existing KPIs of OSC supply chains through a systematic literature review. The remainder is structured as follows. Section 2 describes the research methodology and procedure. Section 3 synthesises published literature and demonstrates the extracted KPIs in economic, social and environmental aspects. The findings and discussion are presented in Section 4. Finally, Section 5 concludes the research implications and recommends future directions.

2 Methods of Review

The performance measurement is suggested to use composite indicators, and frameworks with a systematic perspective are recommended to guide the analysis. Ahi and Searcy [12] extracted 2555 unique performance metrics of supply chains through a structured content analysis, the majority of which fall into the groups of economic, environmental social focuses. Pan, Zhang, Xie and Ping [13] developed a set of KPIs from the economic, social and environmental perspectives to benchmark modular integrated construction projects. The Triple Bottom Line (TBL), which systematically examines the social, environmental and economic impacts, is therefore recognised as a sound starting point for developing comprehensive performance metrics [14, 15]. This research adopted TBL and identified KPIs of OSC supply chains drawing on a comprehensive review of related articles. A three-stage review following the systematic literature review method was proposed (Figure 1) [16].

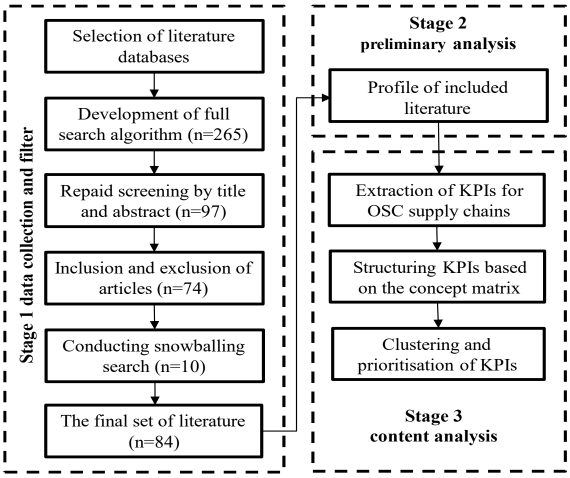

Figure 1. Main stages of research procedure

In Stage 1, a comprehensive paper search was conducted using Web of Science and Scopus. The search strings combined OSC related keywords like "offsite construction", "prefab*", "industriali* construction", and "modular construction" (see Pan, Zhang [17]); supply chain related ones like "supply chain*" and "value chain*"; and KPI related ones like "key performance indicator*", "performance metric*", "performance measurement", "performance evaluation", "performance assessment", "driver*", and "critical success factor*". 265 papers were retrieved and screened to collect articles that: (1) were published in peer-reviewed journals or conference proceedings; (ii) were in engineering and construction management field; and (iii) were written in English. For comprehensive coverage, a snowballing search was conducted to collect relevant articles outside the scope of the predefined search strings [18]. Finally, 84 articles were considered eligible, including 74 from the initial screening and 10 from the snowball search.

In Stage 2, a preliminary analysis was performed to classify the selected papers according to year, location, source and research method. These results clarified the previous research process and expedited to assess the main issues in supply chain performance measurement.

In Stage 3, KPIs were extracted through content analysis and organised based on the concept matrix according to Webster and Watson [16]. The initial indicators were catalogued against the citing sources, and those with similar meanings were merged. Then, the KPIs were classified based on TBL and further clustered into different performance fields. For prioritisation, the KPIs were ranked based on the frequency of occurrence.

3 Review analysis and findings

3.1 Profiles of publications

The included articles were first analysed in terms of year, location, journal, and research methods. Figure 2 illustrates the annual distribution of the 84 included articles from 2000 to 2021. The number of publications remained low for 14 years, with a sharp and progressive increase since 2014. Figure 3 shows the geographical distribution of the articles based on the author affiliation. Hong Kong SAR (21 articles; 25%) accounted for the largest number of publications, followed by Australia (15, 17.8%) and Mainland China (11, 13.1%). As for publication sources (Figure 4), Journal of Construction Engineering and Management, Journal of Clean Production, and Construction Engineering and Economics were the leading sources of research in performance measurement for OSC supply chains. Figure 5 indicates that most of the included articles (39) adopted hybrid research methods, followed by case study and literature review. Interview was also widely adopted (36) but commonly together with other research methods.

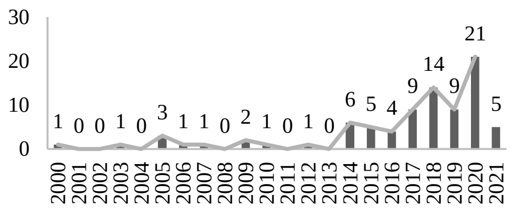

Figure 2. Years of publications

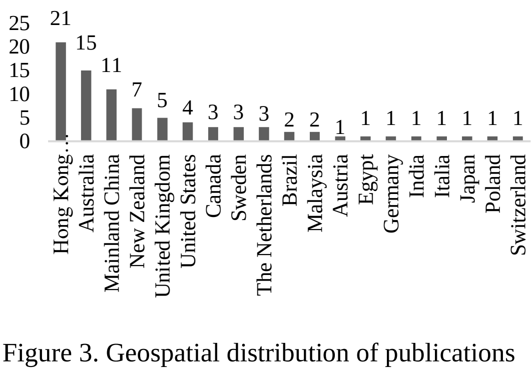

Figure 3. Geospatial distribution of publications

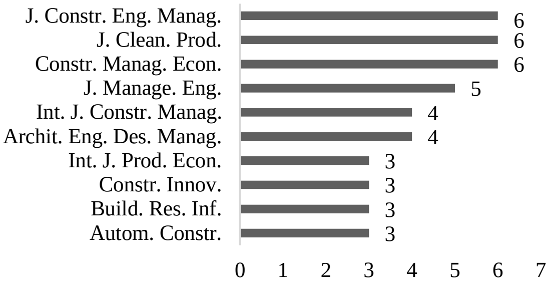

Figure 4. Source of retrieved publications

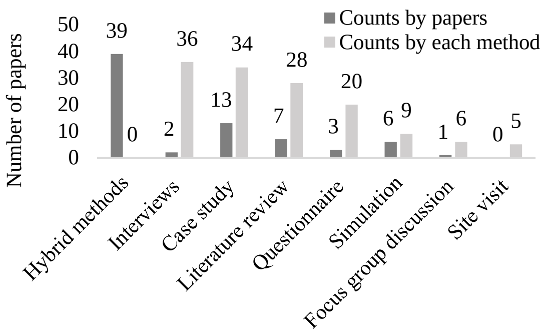

Figure 5. Research methods

3.2 KPIs of OSC supply chains

This study aims to identify KPIs that are indicative of the performance of OSC supply chains in terms of a certain activity or as a whole. Results indicate that limited publications have provided a comprehensive list of KPIs. Most articles (86.9%) mentioned economic KPIs, while 56.0% and 31.0% of articles considered social and environmental KPIs, respectively, as illustrated in Figures 6-8 and described below.

3.2.1 Economic KPIs

To indicate OSC supply chains' economic success, KPIs were found related to ten performance fields: namely, cost, time, quality, productivity, flexibility, efficiency, predictability, reliability, leanness, and utilisation (Figure 6).

Cost performance was pointed out as the most significant performance field in the economic aspect. The most frequently mentioned KPI in this field was lifecycle cost (e.g., [19]), which can be further measured by the associated cost across the entire supply chain. The breakdown of lifecycle cost, accounting for a large portion of cost performance, were described as process-based costs, including assembly cost (mentioned in 16 articles), transportation cost (14), inventory-related cost (13), production cost (7), and overheads (7) that support the processes of creating a product or service (e.g., [20]). Instead, other researchers used resource-related cost, including KPIs of labour cost, capital cost, and material cost (e.g., [9]). The remaining KPIs included cost variance (18), return on investment (12), and financial strength (6). Cost variance that ranked third according to the frequency of occurrence in the retrieved papers presents deviations of actual cost against planned budget or benchmark (e.g., [8]). Since the promotion of OSC supply chains can only be realised when stakeholders earn benefits [21], return on investment measuring the value-added benefits has attracted great attention (e.g., [22]). Last but not least, financial strength mentioned in six papers was significant to the success of OSC deliveries, due to the high initial investment and financial pressure faced by suppliers (e.g., [23]). There is overlap between various cost performance indicators, and different stakeholders should deliberate on the selection of KPIs according to their business goals.

Time performance accounted for the second large portion of economic performance. Literature in the supply chain field identified time-based competition as a management area to evaluate OSC supply chains' responsiveness, representing less process time and a shorter order fulfilment cycle [24]. Time-related KPIs of OSC supply chains are listed in reverse order based on the frequency of occurrence: time variance, cycle time, assembly time, delivery time, ontime delivery rate, and manufactory time (e.g., [25-27]). To ensure the ontime delivery, stakeholders can use these KPIs in combination to measure time performance of each stage against cycle time or planned schedule, thus helping them develop appropriate responsiveness interventions.

The third performance field was productivity. It measures the quantity of products and services obtained through unit resource expenditure, such as labour productivity, equipment productivity, and material and energy productivity (e.g., [28, 29]).

Flexibility, the ability to meet varied customer requirements and frequent order changes, ranked as the fourth performance field. On the one hand, flexibility is manifested in responding to varied customer requirements, indicating the balance between customisation and standardisation (e.g., [9, 23]). Standardisation may ensure efficiency but might sacrifice customisation, while customisation can be challenging to scale. On the other hand, flexibility is the possibility to address short term changes and external disruptions. As such, the importance of supplier and material alternatives, inventory buffer, and other performance regarding responsiveness to changes were emphasised in 19 articles (e.g., [30, 31]).

Quality ranking the fifth place consists of two aspects: the major one being defects and rework, and the other being compliance with building specifications. The terms extracted from the selected publications, such as quality-reduced defects, cost of rework, changeover cost, and quality cost, were listed under the group of defects and rework (e.g., [9, 29, 30]). In case of product defects, extra money and time need to be spent, affecting the operations of downstream activities. Besides, quality was also described as compliance with codes and standards, though rarely mentioned [29].

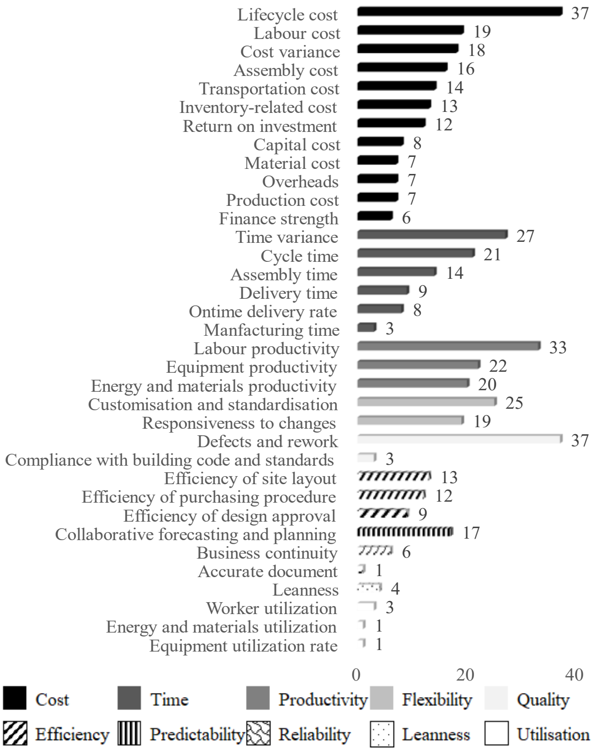

Figure 6. KPIs of OSC supply chains in the economic aspect

The following field was efficiency, measuring how companies and processes harness resources to achieve the highest output with the least inputs. The efficiency-related KPIs focus on resources optimisation for specific operations across supply chains. According to the results, researchers paid particular attention to the efficiency of site layout (13), purchasing procedures (12), and design approval (7), as listed in descending order [9, 32, 33].

The final four were less-mentioned performance fields. Predictability mentioned in 17 articles is critical to stable delivery by forecasting and planning time, cost, and demand of OSC supply chains [30]. Reliability was discussed to reflect the accurate and stable delivery of suppliers' products and service. Terms like accurate, reliable and timely time and material flows were identified as conducive to business continuity [25]. Accurate documents, such as accurate delivery notes, stock records and working instructions, was seen as a contributor to delivery accuracy [34]. The penultimate performance field was leanness, reflecting the item-level management and automation level in OSC supply chains [35]. In the last performance field, worker, energy and material, equipment utilisation were identified as major KPIs, which could be calculated as the rates of utilised resource against the total available time/volume of resources for a project [26].

3.2.2 Social KPIs

Concerns about the social performance of OSC supply chains have been increasing in recent years. The extracted social KPIs were clustered into the following five performance fields: impact on project, impact on industry, information flow, employee concerns, and impact on community (see Figure 7).

One of the most significant social performance fields was the impact on project. The social KPI, collaboration and coordination, was most frequently mentioned in the retrieved papers. Enhanced by advanced technology, it has provided an innovative way that stakeholders could pool their resources and knowledge together and work towards the overall goals of the entire process rather than their own goals [7]. The second KPI was trust and long-term relationship. Trust between various participants was proved helpful in smoothing the construction process, thereby increasing supply efficiency and allowing flexibility when facing uncertainty [36]. In addition, long term bonding between suppliers and contractors leads to greater synergy, transparency, openness, sharing and trust [37]. Researchers increasingly valued the partnership and meanwhile concerned about conflicts and disputes that damage the cooperative relationships. Therefore, the ability to solve conflicts and disputes was regarded as the third KPI in the performance field [38]. Following that, stakeholders' satisfaction that reflects their level of satisfaction with the finished product or services, ranked as the fourth KPI. The least mentioned KPI in this performance field was about accident, which together with conflicts and disputes were considered to damage the stakeholders' satisfaction and may have severe social impact [36].

Social performance regarding the impact on industry was viewed equally important as they affect the industry's decision on the OSC adoption. KPIs in this field focused on technology and innovations application (32), which stimulates the development of OSC by improving productivity [26]. In the following KPIs, the second KPI of government support and the fourth one of regulation and standards development, are also significant incentives to promote OSC [36]. Competitiveness and leadership mentioned in 7 articles ranked the third place, as products competitiveness and enterprises' leadership are a necessary piece of organisational success [9]. Next two KPIs (i.e., research and development, intellectual property protection) indicate the stakeholders' attitudes towards and investment in technological upgrading of OSC supply chains [39, 40].

Information flow was analysed as a performance field closely bound to information technology. It included information sharing and communication [36], information visibility and traceability [35], information security [41] and information transparency [42]. Especially information sharing and communication, the KPI representing the exchange of data between various organisations and professionals is a significant indicator of the cooperation level and further contribute to the success of OSC supply chains.

Next performance field was employees' concerns, including health and safety and job satisfaction [37]. As labour shortage has become severe in the construction industry of many developed economies, the improvement of work conditions is crucial to establishing OSC supply chains [36]. Companies that take measures to increase their job satisfaction by improving workers' welfare and career development will in return have a positive impact on the corporate image and project profits [36].

Impact on the local community received relatively less attention. Projects which rely heavily on local areas' infrastructure should serve the local community [43]. Corporate responsibility measures stakeholders' commitments to supporting local general welfare undertakings and complying with laws and regulations [37], while impacts on local economy measures how a project influences the fiscal revenue and employment in the region [44].

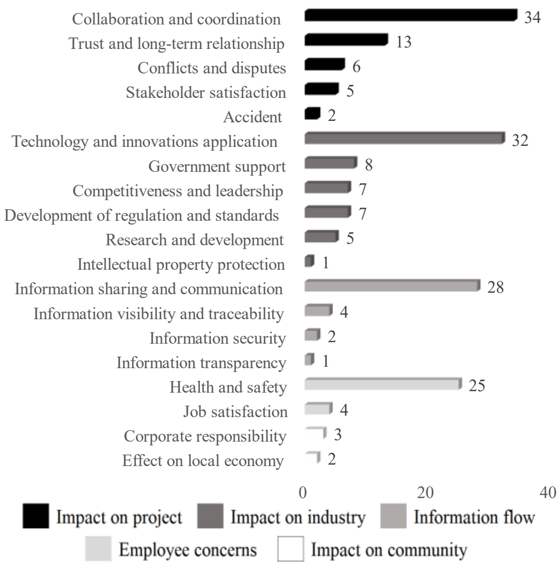

Figure 7. KPIs of OSC supply chains in the social aspect

3.2.3 Environmental KPIs

The environmental KPIs involved four performance fields: waste and pollution, resource use and recycling, environmental commitment and greenhouse gas emissions (Figure 8).

First, the major environmental concern was waste and pollution generated in the whole supply chain, as it could reduce the industry's and community's willingness to uptake the OSC approach. As such, it is essential to take waste-related KPIs (i.e., waste disposal, waste reused and recycled) [45] and pollution-related KPIs (i.e., water pollution, air pollution, and noise pollution) into environmental consideration when establishing OSC supply chains [43].

Resource consumption accounted for the second large portion of environmental performance. The extraction and processing of building material may result in soil degradation, water shortages, and global warming. The reduction in the consumption of water, energy and other natural resources is a measure of the environmental capability of resource saving and recycling [36].

Environmental commitment was another important performance field, including environmental statutory compliance and environmental targets and activities. The former one refers to compliance with environmental legislation, policies and standards, helping avoid adverse environmental impacts [46]. The latter one is to measure impacts on the achievement of environmental goals [36]. Companies throughout OSC supply chains are the mainstays to improve environmental performance and are responsible for publishing their environmental goals.

The last performance field about greenhouse gas emissions was regarded as one of the commonly tracked environmental impacts in the construction industry. Greenhouse gas emissions are usually converted into carbon accounting for measurement. The primary step to keeping them at an acceptable level is estimating carbon accounting throughout the whole supply chain [47].

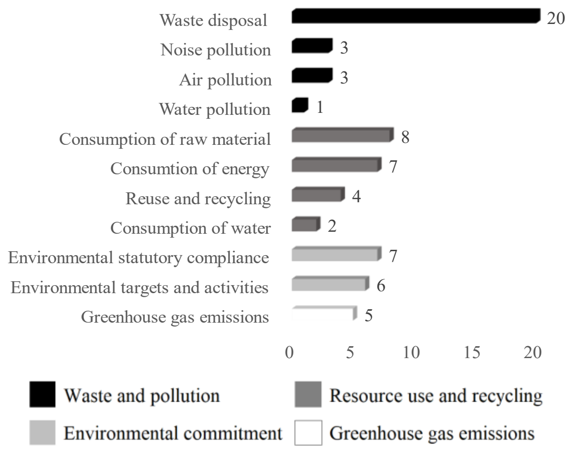

Figure 8. KPIs of OSC supply chains in the environmental aspect

4 Discussion

This study identified a holistic list of KPIs for OSC supply chains through a systematic literature review. All the identified KPIs covering economic, social, and environmental aspects can be structured as illustrated in Figure 9: (1) the radial direction indicating the hierarchical relationships between a particular indicator and higher-level performance; (2) the circular direction describing the clusters of KPIs that assess a specific performance field and aspect. Figure 9, taking the environmental KPIs as an example, shows that the environmental aspect (inside layer) is comprised of four performance fields (middle layer), under which there are a total of 11 environmental KPIs (outermost layer). Similarly, economic and social KPIs are also distributed accordingly, and the specific KPIs of the outermost layer are described in the sections above.

The KPIs are intended to be broadly applicable, but there are some overlaps and limitations. For example, lifecycle cost can be regarded as the sum of each process's expenditure [20]. Whether to use lifecycle cost or some specific process costs depends on different stakeholders and segments of OSC supply chains [43]. Besides, previous research mainly focused on the economic performance of OSC supply chains rather than social and environmental aspects, which underscores the deficiency in these two core areas of current measurement efforts. With the occurrence count of each KPI, this study not only identified common KPIs, but also found that several KPIs received relatively little attention in the past. In addition, modular construction representing the highest level of OSC is the main trend. Research on supply chain performance measurement for modular construction should build on that of OSC supply chains and deliberate on the differences with component, element and system delivery.

The proposed KPIs derived from various publications enhance the knowledge base of OSC supply chains. However, the presented work is only a fundamental step to establishing a bespoke performance measurement toolkit or method. Several improvements for future research have been identified as follow. First, researchers should consider the entire spectrum of supply chains and the overall performance, particularly in social and environmental aspects [11]. Second, as these KPIs are only derived from literature and lack practical verification, it requires triangulation of multiple forms of evidence subject to validity testing, such as interviews and questionnaire surveys [7]. Third, a quantitative analysis should be conducted to evaluate the interaction and relative importance of the proposed KPIs [33]. It is meaningful but challenging to explore how to balance the KPIs to attain the best sustainability performance. Finally, empirical research is required to validate the proposed framework.

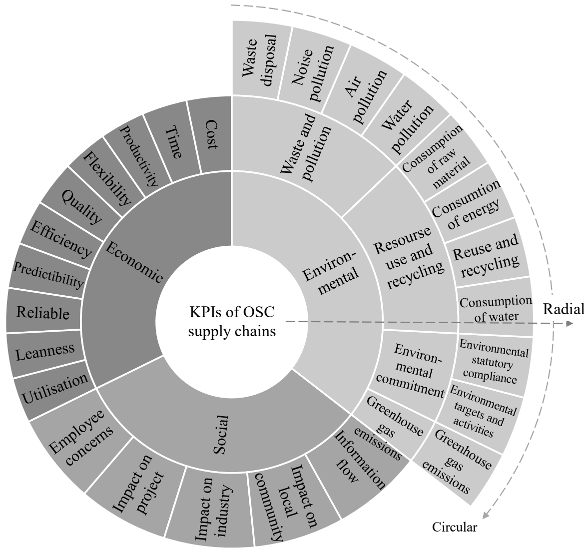

Figure 9. The framework of OSC supply chain KPIs (take environmental KPIs as an example)

5 Conclusions

This research attempts to provide a systematic review of existing publications on KPIs of OSC supply chain and suggest future research. An initial performance measurement framework, consisting of 35 economic, 19 social and 11 environmental KPIs, was developed to demonstrate how they jointly measure the performance of OSC supply chains. Although the framework is intended to be broadly applicable, organisations should select the most appropriate KPIs to evaluate whether their performance is in line with goals. In addition, more attention should be paid to the neglected KPIs, especially in social (e.g., job satisfaction and impact on local economy) and environmental (e.g., pollutions and greenhouse gas emissions) aspects, to support the enhancement of OSC supply chains in a systematic and sustainable manner.

This review contributes insights into the strategic considerations of performance measurement but is still far from meeting requirements for practice. Consistent performance measurement based on the initial framework should be further refined to support the industry's and community's decision making on OSC supply chain selection and evaluation. As discussed, future research focusing on modular construction will validate and transform the selected KPIs into a total factor or a multidimensional assessment method, with quantifiable or qualitative descriptions of the indicators and the weighting system. The proposed measurement will be verified using real-world cases to demonstrate how OSC supply chains could benefit the construction industry, local community and ecological environment.

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