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A Systematic Review of Quality Management of Offsite Construction

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ABSTRACT

Offsite Construction (OSC) continues to gain popularity for faster, safer, cheaper and more sustainable construction project delivery. An improved quality performance is a chief selling point in the advocacy for the widespread adoption of OSC. Paradoxically, quality issues that arise in OSC projects can be extremely costly. However, quality management (QM) is underexplored in the growing OSC literature. This paper critically reviews the QM of OSC literature to uncover the state-of-the-art and proffer recommendations for future research. 38 articles, selected from Scopus and Web of Science, published from 2009 to 2021 and distributed across 20 journals, were selected through a systematic literature review supplemented by a snowball search. An overview of QM of OSC research is provided based on the yearly distribution of articles, country/territory of affiliation, journal sources, OSC types, project life cycle stages and technologies utilised. The findings revealed a growing interest in the sub-domain. The articles were categorised under six topics: post-production quality assessment, rework and defect management, quality risk management, process improvement, requirements management and quality performance factors. This paper also proposes future research directions based on the prevailing knowledge gaps.

KEYWORDS

Offsite construction; Quality management; Quality assessment; Offsite construction quality, Systematic literature review

INTRODUCTION

Offsite Construction (OSC) continues to gain popularity worldwide as an antidote to the construction industry's challenges (Zheng et al., 2020). As OSC makes inroads in the construction industry, the body of knowledge surrounding it is also expanding (Hosseini et al., 2018) to undergird its successful implementation. Previous studies have reviewed OSC research from varying perspectives. Amidst the proliferation of review studies in OSC, QM remains an underexplored sub-domain. Interestingly, in the advocacy for the widespread adoption of OSC, one of the chief selling points is the quality improvements induced by the transfer of a large proportion of construction work to a more controlled factory environment (Bertram et al., 2019). For instance, Japan's increasing demand for modular buildings has been attributed to their superior quality (Bertram et al., 2019). Paradoxically, quality issues encountered in OSC projects can be extremely costly and time-consuming to remediate (Xu et al., 2020). These quality issues could erode OSC's gains over conventional construction methods, as in the B2 tower project in New York, USA (American Institute of Architects, 2019).

The criticality of quality performance for OSC project success is not reflected in the existing literature since it has not been revealed as a topical area in the previous reviews. Rudimentary issues such as the factors influencing quality performance have yet to be fully explored. The existing literature is primarily skewed towards product quality assessment and quality control. A high premium is seemingly placed on defect detection instead of defect prevention. The evolution of QM to total quality management (TQM) appears to have been lost on OSC. Although interest keeps rising for higher-level OSC, the research in this field has focused more on level 2 OSC. Hosseini et al. (2018) noted that the general OSC literature is product-biased, with a scarcity of studies relating to operational and management issues. Thus, the case is made for review-based research focusing specifically on the QM of OSC. This paper aims to systematically review the QM of OSC literature to reveal the status and dominating focus to stimulate further research. The yearly distribution of articles, country/territory of affiliation, OSC types, project life cycle stages and technologies utilised are overviewed.

METHODS

This research adopted the systematic literature review (SLR) approach. The first step was identifying relevant search terms (Table 1) and academic databases. The Scopus and the Web of Science (WoS) databases were selected to retrieve the QM of OSC articles, mainly because of their extensive coverage. The initial search took place in July 2021, and a final search was undertaken at the end of December 2021. The initial search query turned in 1,386 documents from Scopus and 90 from WoS. Conference papers and non-English documents were then excluded. A confinement strategy was also employed to eliminate articles incongruent with this review. Articles from non-related fields of study (chemistry, telecommunications and the like) were automatically excluded. The results were further merged to identify and remove duplicates, leaving a combined total of 324 articles. The results were then manually reviewed to eliminate any remaining unrelated and irrelevant articles. Initially, 133 articles were selected after their titles, keywords, and abstracts had been vetted. Those OSC-related articles with no quality focus but mentioned quality en passant in their abstracts were excluded. Eventually, 33 articles were selected after comprehensively reviewing all 133 documents. A snowball search of the reference lists of the 33 selected articles also turned up 5 additional articles. Therefore, 38 articles distributed across 20 journals (Table 2) were selected for further analysis. The relatively small sample size suggests the dearth of literature on QM of OSC, underscoring the need for this review.

Table 1. Search terms/keywords adopted in this literature review

Aspect	Keywords
OSC	*"modular building", "modular construction", "modularisation", "modularity", "modular system", "modular integrated construction", "permanent modular construction", "volumetric modular construction", "prefabrication, "prefabricated building", "prefabricated construction", "preassembly, "prefab" "prefabricated prefinished volumetric construction", "precast construction", "offsite construction", "offsite production", "offsite fabrication", "offsite manufacturing", "offsite MMC", "industrialised building", "industrialised building system", "industrialised construction", "system building", "non-traditional building", "modern methods of construction", "volumetric construction"*
QM	*"quality", "total quality", "construction quality", "quality management", "quality assurance", "quality control", "quality inspection", "total quality management", "Strategic quality management", "quality assessment", "quality performance", "quality evaluation", "construction quality", "conformance", "tolerance", "defect", "rework", "deviation", "requirements"*

Table 2. Sources of QM of OSC research articles

Source	Articles
Automation in Construction	12
Journal of Computing in Civil Engineering	4
Sustainability	3
Construction Management and Economics	2
Buildings	2
Journal of Construction Engineering and Management	1
Journal of Management in Engineering	1
Journal of Cleaner Production	1
Journal of Building Engineering	1
Engineering, Construction and Architectural Management	1
International Journal of Construction Management	1
Applied Sciences	1
ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering	1
Multimedia Tools and Applications	1
Measurement	1
Advances in Materials Science and Engineering	1
Journal of Asian Architecture and Building Engineering	1
Journal of Intelligent and Robotic Systems	1
International Journal of Advanced Manufacturing Technology	1
Malaysian Construction Research Journal	1
Total	**38**

RESULTS AND DISCUSSION

Publication trend of QM of OSC articles

The selected studies spanned from 2009 to 2021 (Figure 1). There has been a general increase in the number of articles published as a steady rise was observed from 2015 upwards. However, in 2016 and 2017, 4 articles were published, and in 2018, no article was captured on the subject. As OSC has gained traction in recent years, this upward trend seems natural. Notably, the highest number of articles were recorded in 2020 and 2021. The steady upward trend suggests a growing recognition of the importance of QM to OSC.

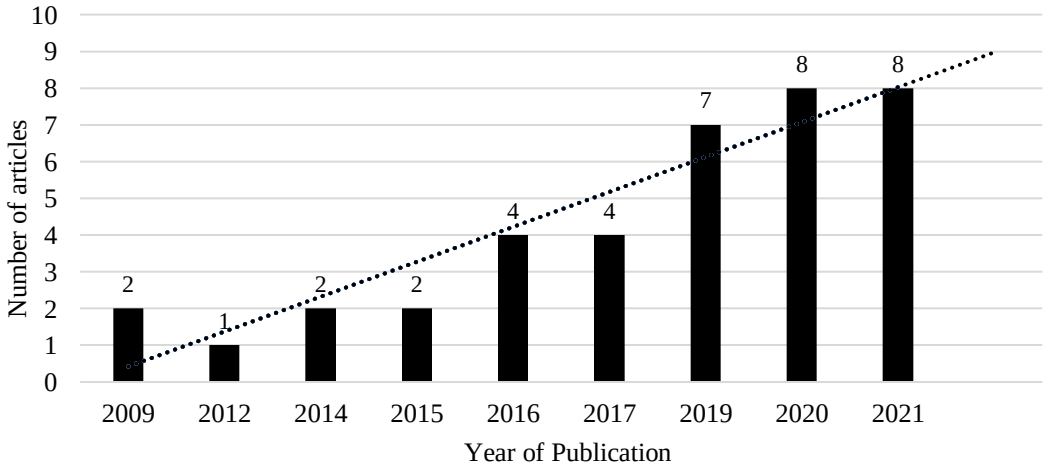

Figure 1. Distribution of QM of OSC articles from 2009 to 2021

Geospatial distribution of articles on QM of OSC

South Korea tops the chart of influential countries/territories in QM of OSC. Authors affiliated with South Korea contributed the highest number of articles, followed by those affiliated with Canada, Hong Kong, Mainland China and Australia (Figure 2). The US, UK, Singapore and Sweden also had fair representation. This finding is consistent with other related reviews (Abdelmageed and Zayed, 2020, Hosseini et al., 2018), as these territories have appeared on the list of top countries contributing to OSC research.

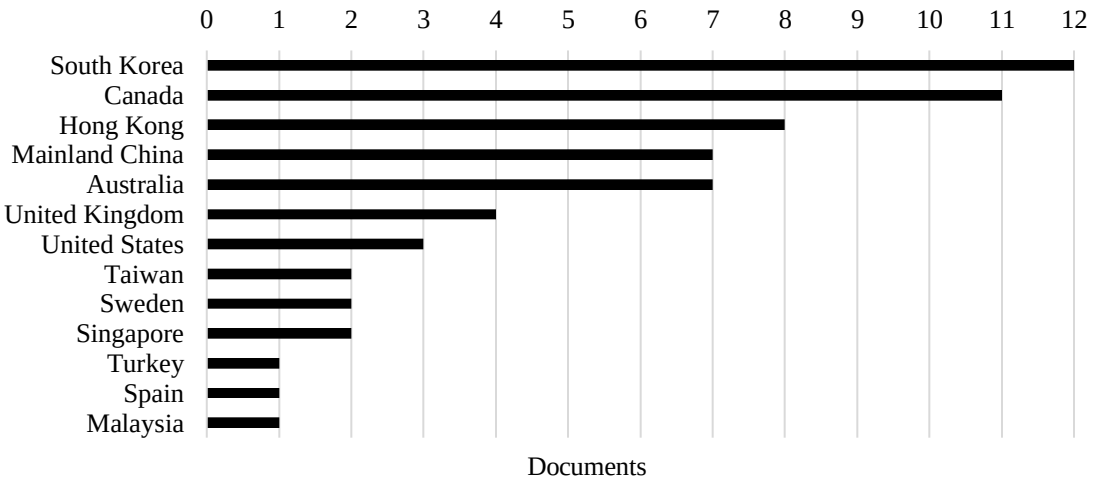

Figure 2. Geospatial distribution of QM of OSC articles

Types of OSC covered in the QM of OSC articles reviewed

Gibb and Isack (2003) categorised OSC into four distinct levels (in increasing order of offsite component): component manufacture and subassembly, non-volumetric pre-assembly, volumetric pre-assembly and modular building. The articles covered were grouped based on this classification of OSC. Non-volumetric OSC has received the most research attention, followed by modular and volumetric OSC (Table 3). The burgeoning demand for level 3 and 4 OSC should translate into an impetus for increased research in higher-level OSC. Although non-volumetric OSC topped the chart, volumetric and modular OSC are not poorly represented either. Notwithstanding, more research attention should be directed towards higher-level OSC.

Table 3. Distribution of OSC Types covered in QM of OSC articles reviewed

OSC Type	Articles
Level 2: Non-volumetric (e.g. precast concrete wall panels)	22 (58%)
Level 3: Volumetric (e.g. precast bathroom units)	2 (5%)
Level 4: Modular (i.e. pre-assembled volumetric units which form the structure and fabric of the final building)	12 (32%)
Generic (i.e. unspecified OSC type)	2 (5%)

Project life cycle phases covered in the QM of OSC articles

OSC follows a multistage production process involving design, manufacturing, transportation and onsite assembly and construction (Yu et al., 2019). Most of the articles focused on the manufacturing phase (Table 4). The operation and transportation stages had received the least attention in the literature.

Table 4. Project life cycle phases covered in the QM of OSC articles

Phase	Articles
Design	4 (11%)
Manufacturing	17 (45%)
Site Assembly & Construction	6 (16%)
Design + Manufacturing	1 (3%)
Design + Manufacturing + Site Assembly & Construction	2 (5%)
Design + Manufacturing + Transportation + Site Assembly & Construction	2 (5%)
Manufacturing + Site Assembly & Construction	2 (5%)
Manufacturing + Transportation + Site Assembly & Construction	1 (3%)
Manufacturing + Site Assembly & Construction + Operation	1 (3%)
Manufacturing + Transportation	1 (3%)
Operation	1 (3%)
Total	38

Technologies utilised in QM of OSC research

Various digital technologies are leverageable for the quality assessment of OSC products (García-Pereira et al., 2020). Multiple researchers have leveraged such technologies to develop methodologies for quality enhancement. Laser scanning was the most prevalent technology utilised in the QM of OSC research, followed by BIM (Table 5).

Table 5. Technologies used in QM of OSC research

Technology	Number of articles
Laser scanning	18
Building Information Modelling	17
Image-based technology (including camera & projector-camera systems)	4
Augmented Reality	2
RFID	1
Integrated sensor and database management system	1

Key Research areas in QM of OSC

The in-depth content review revealed six distinct QM of OSC research areas. Table 6 presents the distribution of articles and proposed future research directions.

1. **Post-production quality assessment.** Li and Kim (2021) and Kim et al. (2019) proposed techniques for inspecting the geometric quality of planar-type prefabricated elements using an integrated laser scanning-flat mirror system. Tran et al. (2021) and Rausch et al. (2021) used a digital twin approach, developed based on laser scanning and BIM integration, for geometric quality evaluation of prefabricated facades and modular structural frames, respectively.
2. **Rework & defect management.** Johnsson and Meiling (2009) profiled defects identified in prefabricated timber modules by analysing quality audit documents of two major industrialised housing companies in the Swedish OSC market. Yu et al. (2019) developed an evaluation model to measure stakeholder impacts on defect occurrence in OSC projects.
3. **Quality risk management.** Dimensional and geometric variability in modularised projects is a source of significant risks (Enshassi et al., 2019). Shahtaheri et al. (2017) developed a framework for using tolerance strategies to proactively manage risks arising from dimensional and geometric variability in modular construction.
4. **Process improvement.** The necessity for continuous improvement in OSC lies in the prevalence of the reactive approach to managing deviations (Meiling et al., 2014). Meiling et al. (2014) applied the plan-do-act-check (PDCA) methodology to improve production for two separate activities in manufacturing timber-framed modules.

5. **Requirements management.** Ha et al. (2016) developed a systematic approach for requirements planning and design optimisation of steel beams used to construct steel-framed modules. Oh et al. (2017) proposed a customer-driven product development methodology for an exportable modular building system.
6. **Quality performance factors.** Gan et al. (2017) identified critical factors affecting the quality of IBS projects during design, manufacturing and construction. More recently, Zhang and Tsai (2021) identified critical factors affecting prefabricated construction quality across 5 categories – man, material, machine and equipment, method and environment.

Table 6. Key Research areas in QM of OSC

No.	Research area	Articles	Future directions
1	Post-production quality assessment	18	• Holistic product quality assessment • Increased automaticity of assessment methodologies • Improved object-detection algorithms
2	Rework and defect management	8	• Comprehensive defect profiling • Empirical research on rework impact on project performance
3	Quality risk Management	5	• Quality risk evaluation & quantification • Quality risk optimisation models
4	Process improvement	3	• OSC process mapping • OSC process simulation modelling • Measurement of process improvement • Identification of improvement areas
5	Requirements management	2	• Quality perception surveys and post-occupancy evaluations • Requirements modelling and traceability
6	Quality performance factors	2	• OSC quality assessment index • Quality Maturity Model for OSC firms

CONCLUSION

Quality in OSC is critical as deviations may lead to high costs and time overruns. Additionally, previous review articles have focused on other areas of OSC, leaving QM largely underexplored. To fill this gap, a systematic literature review was undertaken to examine the status quo and identify the future directions of the QM of OSC research. A total of 38 articles, selected through a systematic process, were analysed. The findings revealed a growing interest in the QM of OSC. Researchers affiliated with South Korea, Canada, Hong Kong, Mainland China and Australia contributed the most. Non-volumetric OSC has received the most attention, followed by modular construction and volumetric OSC. The manufacturing phase has received the most attention, while the operation phase has received the least. Laser scanning and BIM were the predominant modern technologies utilised in the QM of OSC research. Six key research areas were discovered from the literature.

Based on the findings, some recommendations are proffered to guide the direction of future research. Quality perception surveys are required to assess client and end-user satisfaction with OSC buildings. Post occupancy evaluation of completed OSC buildings shall provide valuable feedback. Testing innovations with specimens of the same material and dimensional characteristics used in real-life projects will provide a more valid proof of concept. Therefore, real-life case studies should be undertaken to validate proposed technological innovations for the quality assessment of OSC products. A holistic quality performance assessment system for OSC projects is required. Quality performance indicators need to be established and aggregated into an index for a more

comprehensive assessment. The feasibility of TQM for implementation in OSC projects requires a thorough investigation. Since OSC is a hybrid of construction and manufacturing, a unique opportunity is presented to apply QM approaches that have proven helpful to the manufacturing industry.

This study contributes to the OSC literature by revealing the status quo of QM of OSC. However, the findings of this article need to be interpreted considering its limitations. The sample selected is subject to limitations inherent in the databases used and the chosen keywords for the search. The likelihood of some literature being overlooked should not be entirely discounted.

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