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A systematic review and meta-synthesis of the barriers of offsite construction projects

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Abstract

Offsite construction (OSC) has been increasingly adopted in the construction industry, especially with increased practical interest in digital transformation in construction, automated production, assembly, and delivery. The uptake of OSC has not however been consistent internationally, and the adoption rate of modular and prefabricated construction is still poor in many developing and developed countries. This review aims to detect and classify the barriers for adopting OSC by assimilating previous research studies. This paper systematically analyses 75 research articles, published in the past decade spanning between 2012 and 2022 inclusive. A total of 47 barriers were identified through this review and the five most frequent barriers were: lack of skills and expertise in OSC within the organization, poor cooperation and integration between stakeholders in the value chain, higher project costs, higher capital cost, and lack of a national standards and design codes for prefabricated components. The analysis offers insights into gaps that exist that could support greater OSC activity globally. Barrier trends by publication year and country are reported to highlight changes in research activity to delineate recommendations for future work to ensure greater uptake.

Keywords: Offsite construction; prefabrication; modular construction; barriers; challenges; review

1. Introduction

For the past decade, offsite construction (OSC) has received greater attention in the architectural, engineering, construction, and facilities management (AEC/FM) sector. OSC refers to the practice of manufacturing and pre-assembling building components, modules, or elements at a location separate from the construction site, typically within a factory or manufacturing facility (van Egmond 2012), which are then transported to the site and assembled to form the final building (Goodier and Gibb 2007). Elnaas (2014), defines OSC as a construction strategy with the primary goal of increasing efficiency, enhancing quality, and reducing environmental impact by employing manufacturing processes within a controlled factory environment. This approach effectively transforms the conventional construction site into an assembly workshop for prefabricated components and/or elements. Achieving this involves the integration of standardization, technology, and labour into an efficient product management process, both onsite and offsite. OSC can cover a range of methods, including modular construction, panelized systems, and volumetric construction.

OSC is portrayed as having the potential to improve the performance of the construction industry as it brings many advantages over traditional onsite construction methods. At the project level, OSC delivers benefits on projects including better predictability of cost and time, faster construction programme, improved health and safety, and better-quality construction (Jansen Van Vuuren and Middleton 2020). At the national level, OSC contributes to a greener built environment, which is particularly important with the construction industry being considered as one of the least environmentally friendly worldwide (Jin et al. 2020). The uptake of OSC has not however been consistent internationally, and the adoption rate of modular and prefabricated construction remains modest. For instance, OSC constitutes to ⍰2, 7, 2, and 3–5%, respectively in the UK, USA, China, and Australia (Steinhardt Dale and Manley 2016). This might appear surprising given the many advantages OSC can offer in addition to having high opportunities, capabilities, and an acknowledged efficient innovative construction sector in such countries (Steinhardt Dale and Manley 2016).

While there are studies that have identified and assessed several barriers associated with OSC adoption in certain countries, no study has undertaken a comprehensive review of all these studies to identify the current gaps and trends concerning the adoption barriers of OSC on a global scale. Therefore, this systematic review aims to detect and classify the barriers for adopting OSC by assimilating previous research studies. Thus, this paper draws evidence from various studies in the form of a meta-synthesis review, involving a thorough search of the literature to clarify the factors that predominate to provide deeper insight into trends over the review decade and to highlight key examples from various countries included in the review. In doing so, it aims to offer a more comprehensive understanding of how the advantages of OSC can be harnessed to boost its adoption, as well as how potential hurdles might impede its adoption when left unaddressed.

2. Methods

A systematic review is a powerful, objective, and replicable methodology employed to investigate existing studies, delineating the scope of knowledge within a particular subject and pinpointing areas necessitating further research (Levy and Ellis 2006). This systematic review paper is designed to offer a comprehensive overview of the existing body of literature. It adheres to the PRISMA statement principles which offers practical approaches that are particularly useful for systematically reviewing literature in social science studies and for conducting comprehensive reviews in this field (Peters et al. 2015). This involves processes of systematic search for peer-reviewed materials, screening, critical evaluation, extracting metadata, and conducting content analysis, as indicated in Figure 1. The selection criteria were primarily based on the direct relevance to the subject matter, while also considering studies related to the subject due to their significant relevance.

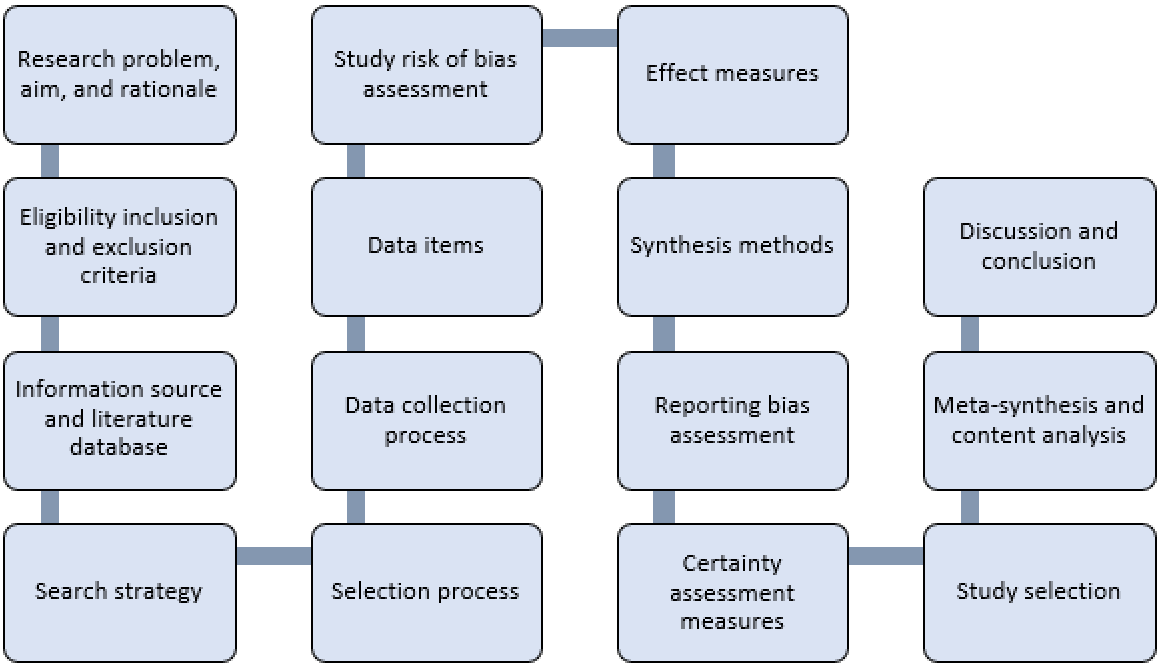

Figure 1: Methodological framework of the study following PRISMA guidelines.

To mitigate bias in this procedure, a research synthesis approach that is objective and transparent was employed, encompassing both quantitative and qualitative studies. The study utilized ScienceDirect and Scopus databases, which are two of the prominent citation index organizations, to gather relevant data. Scopus covers ⍰99.11% of the journals indexed in Web of Science, reflecting its extensive reach (Singh et al. 2021). Therefore, the authors opted to use Scopus for their research, given its significant coverage and frequent use in prior studies, particularly for systematic reviews in various fields, such as OSC. The terms ‘offsite construction’ (OSC), ‘off-site construction’, ‘offsite manufacturing’ (OSM), ‘off-site manufacturing’, ‘offsite production’, ‘off-site production’, ‘prefabrication’, ‘pre-fabrication’, ‘prefabricated construction’, ‘pre-fabricated construction’, ‘prefabricated prefinished volumetric construction’ (PPVC), ‘modular construction’, ‘modular integrated construction’ (MIC), ‘volumetric construction’, ‘modern method of construction’ (MMC), ‘industrialized buildings system’ (IBS), ‘industrialized construction’, and ‘industrialized housing building, were used, combined with the terms ‘barriers’, ‘challenges’, ‘constraints’, ‘limitations’, ‘obstacles’, ‘factors’, impediments ‘, ‘problems’, ‘hindrances’, to select any papers where they were found in the title, abstract and/or keywords. There was no limit on the country of studies, but only studies written in English were included. This generated 688 papers (as of January 2023). Thus, to narrow down this wide scope and to focus closely on the barriers of OSC, the search was amended to include articles published within the time period of 2012 to 2022 only. Thus, 183 papers were identified; these were narrowed down further following a rapid screening of titles and abstracts manually by the research team as a means to ensure relevance to timeframe and location for analysis of meta data. Subsequently, the full text of the remaining papers were assessed for eligibility. The resultant 75 papers were deemed valid for inclusion and were finally identified for this systematic review. Figure 2 presents a flow diagram illustrating the study selection process.

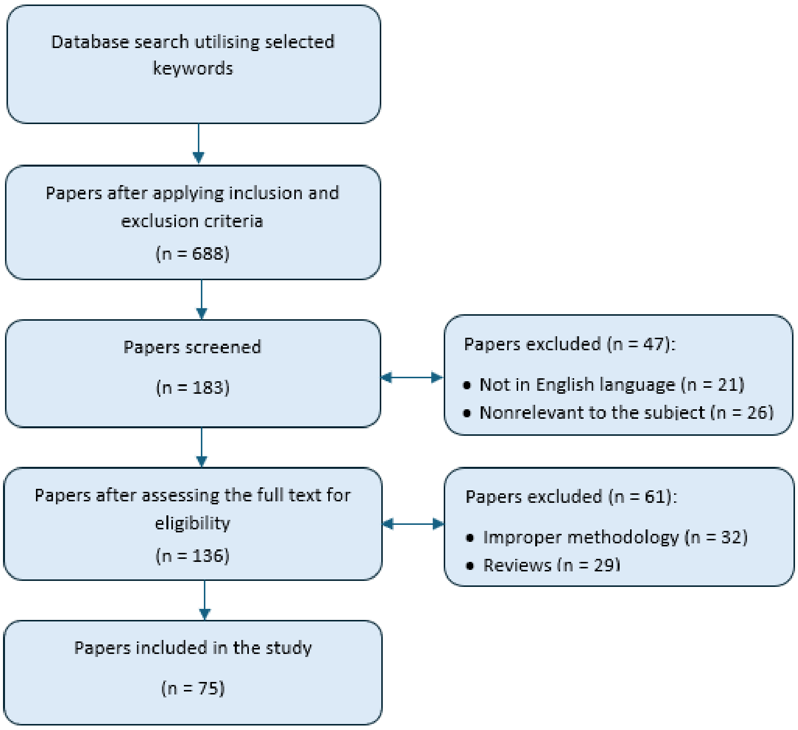

Figure 2: Diagram of reporting items for the study review process.

3. Results and discussion

Figure 3 shows the distribution of the reviewed papers by year, covering a period of one decade, spanning between 2012 and 2022 inclusive. The annual publications pattern confirmed that research interest in OSC has been steadily growing over the past decade, with a noticeable rise in 2022; 25.3% of reviewed articles were published in this year alone, noting, the global Covid pandemic may have indeed impacted on the production of research papers, and whilst this is perhaps maybe a common conclusion to reach, we have no evidence to confirm or refute this; nevertheless, the growth in outputs prevails. This pattern could indicate a growing dedication among practitioners, researchers, and stakeholders to addressing the obstacles to facilitate OSC adoption in the upcoming decades.

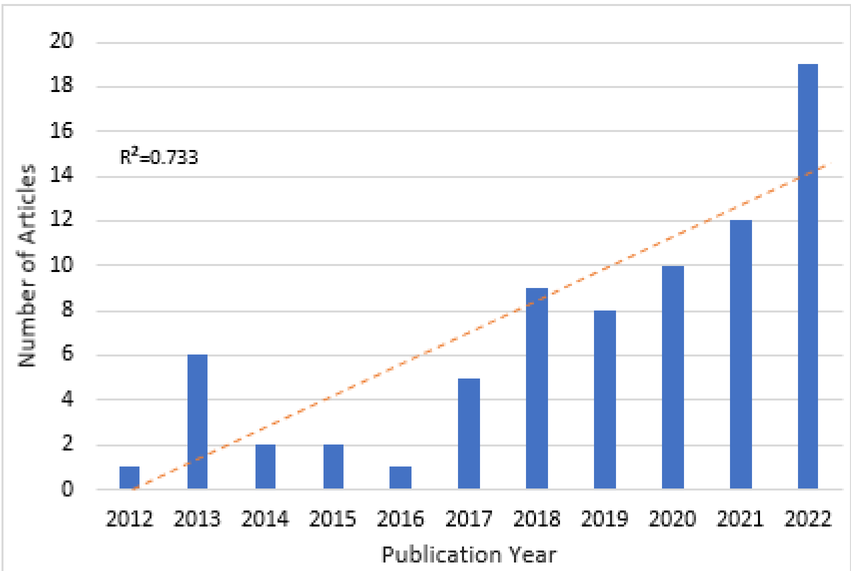

Figure 3. Annual publications trend on OSC from 2012 to 2022.

Figure 4 indicates that the 75 reviewed studies were conducted in 19 countries spanning five continents, including Europe (e.g. UK), Asia (e.g. China), Oceania (e.g. Australia), North America (e.g. USA), and Africa (e.g. South Africa). Therefore, the findings of this review study offer a comprehensive global perspective on the barriers to OSC adoption. Figure 4 also demonstrates that the study encompasses papers from both developed economies (e.g. UK, Australia) and developing economies (e.g. China, Malaysia), ensuring that the results encompass evidence from a diverse range of countries, including both developed and developing ones. The geographical distribution shows that over half of the reviewed articles originated from Asia (61%), with China's contribution being particularly significant. Research on OSC in China alone accounts for 48% of the reviewed articles, despite numerous government policies worldwide promoting the general adoption of OSC. For example, there were only four papers identified in the UK, which perhaps does not reflect the flurry of OSC initiatives during this review period. Conversely, there was no representation from South America and only a few articles from North America and Africa, particularly from highly efficient and innovative construction sector countries like the USA. This suggests a low priority for implementing the OSC method in these regions. Therefore, future research should consider including these countries.

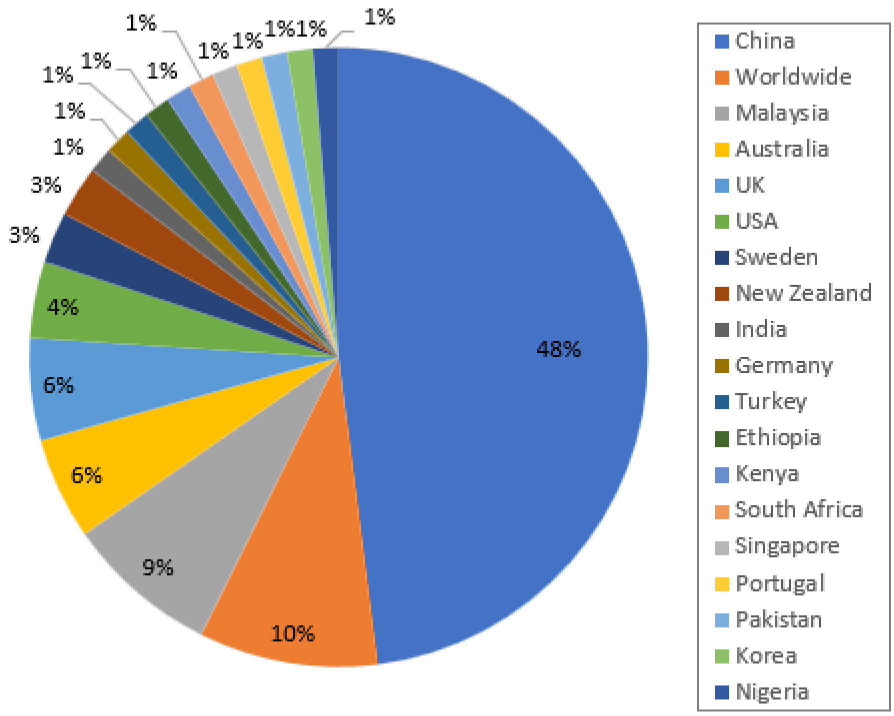

Figure 4. Geographical distribution of the included OSC articles.

Related to the various government drives, it is also important to note that there are different terms used in the literature for OSC, such as prefabricated construction, offsite manufacturing (OSM), and modern methods of construction (MMC)—although MMC technically covers a whole array of technologies, including OSC, not all MMC is OSC (Nadim 2012). Further, it is acknowledged that OSC is termed differently globally. For example, it is more widely known as modular integrated construction (MiC) in international studies (Wuni and Shen 2020; Wuni et al. 2022; Tsz Wai et al. 2023; Wuni and Shen 2023; Wuni et al. 2023a, 2023b) industrialized building system (IBS) in Malaysia (Anuar et al. 2014; Yunus and Yang 2016; Akmam Syed Zakaria et al. 2018; Ali et al. 2018; Nasrun et al. 2019; Ismail et al. 2022), and modular construction in USA (Azhar et al. 2013; Jeong et al. 2022). Whilst we included these various terms in the review search, there may be iterations of the terms that were not captured, therefore the distribution by country is perhaps not fully reflective of all work within the realm of OSC in each country.

The reviewed article's project types are shown in Figure 5; 72% (54 articles) of the research related to construction generally, whereas 21% (16 articles) were specific to house construction (e.g., Zhang et al. 2014; Ali et al. 2018; Marinelli et al. 2022), 4% (three articles) to infrastructure (Larsson et al. 2014; Koronaki et al. 2021; Ismail et al. 2022), and 3% (two articles) to commercial (Azhar et al. 2013; Correia et al. 2020), respectively. These categories of project types were delineated from the articles.

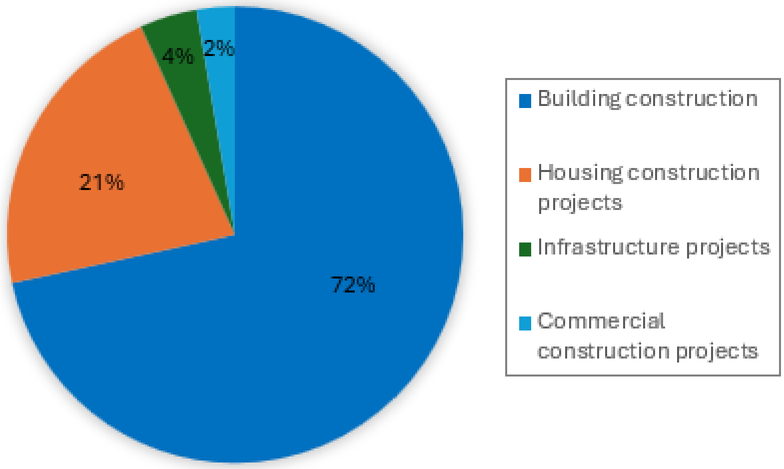

Figure 5. Distribution of OSC project types in the reviewed articles.

3.1 Barriers

Table 1 summarizes the identification of 47 barriers from the literature. During the review of each article, a frequency count of each barrier was made and referenced to the source article. The barriers were subsequently ranked in ascending frequency order, and categorized using the PESTLE analysis approach (political, economic, social, technical, legal, and environmental; noting that in this instance, political and legal barriers were grouped together) as a means to structure the discussion in this review.

Table 1: Barriers to OSC identified in the reviewed articles.

ID	Barriers	Source	PESTLE category	Freq.	Rank
B1	Lack of skills and expertise in OSC within the organisation	Mohammed et al. 2012; Shahzad and Mbachu 2013; Motiar 2014; Anuar et al. 2014; Zhai et al. 2014; Chao et al. 2015; Xue et al. 2017; Gan et al. 2017; Lee and Kim 2017; Li et al. 2017; Ali et al. 2018; Akmam Syed Zakaria et al. 2018; Gan et al. 2018a, 2018b; Zhang et al. 2018; Jiang et al. 2018; Han and Wang 2018; Hong et al. 2018; Ji et al. 2018; Wu et al. 2019; Nasrun et al. 2019; Wuni and Shen 2020; Yuan et al. 2020; Dang et al. 2020; Jiang et al. 2020; Correia et al. 2020; Li et al. 2021; Gumusburun Ayalp and Ay 2021; Ji et al. 2021; Zhang and Tsai 2021; Koronaki et al. 2021; Ismail et al. 2022; Marinelli et al. 2022; Ribeiro	Social	49	1

		et al. 2022; Thajudeen et al. 2022; Yang et al. 2022; Zolghadr et al. 2022; Lan et al. 2022; Wu et al. 2022; Pervez et al. 2022; Wuni et al. 2022; Agapiou 2022; Feldmann et al. 2022; Kedir et al. 2022; Lopez et al. 2022; Navaratnam et al. 2022; Li et al. 2023; Akinradewo et al. 2023; Tsz Wai et al. 2023			
B2	Poor cooperation and integration between stakeholders in the value chain	Mohammed et al. 2012; Azhar et al. 2013; Anuar et al. 2014; Zhai et al. 2014; Motiar 2014; Chao et al. 2015; Luo et al. 2015; Xue et al. 2017; Akmam Syed Zakaria et al. 2018; Hwang et al. 2018; Zhang et al. 2018; Jiang et al. 2018; Han and Wang 2018; Gong et al. 2019; Li et al. 2019; Wu et al. 2019; Li 2020; Jiang et al. 2020; Yuan et al. 2020; Wuni and Shen 2020; Gumusburun Ayalp and Ay 2021; Koronaki et al. 2021; Zhang and Tsai 2021; Ismail et al. 2022; Marinelli et al. 2022; Pervez et al. 2022; Wu et al. 2022; Zhang et al. 2022; Wuni et al. 2022; Tsz Wai et al. 2023; Wuni et al. 2023a, 2023b	Social Technical	32	2
B3	Higher project costs	Anuar et al. 2014; Motiar 2014; Luo et al. 2015; Xue et al. 2018; Zhang et al. 2018; Jiang et al. 2018; Ali et al. 2018; Han and Wang 2018; Hong et al. 2018; Hwang et al. 2018; Gan et al. 2018b, 2019; Wu et al. 2019; Correia et al. 2020; Dang et al. 2020; Jiang et al. 2020; Yujin et al. 2021; Shamsuddin et al. 2021; Li et al. 2021; Feldmann et al. 2022; Navaratnam et al. 2022; Agapiou 2022; Kedir et al. 2022; Lopez et al. 2022; Wu et al. 2022; Wuni et al. 2022; Zolghadr et al. 2022; Li et al. 202	Economic	28	3
B4	Higher capital cost	Anuar et al. 2014; Motiar 2014; Zhai et al. 2014; Zhang et al. 2014; Chao et al. 2015; Luo et al. 2015; Yunus and Yang 2016; Xue et al. 2018; Ali et al. 2018; Hong et al. 2018; Hwang et al. 2018; Jiang et al. 2018; Zhang et al. 2018; Gan et al. 2018a, 2019; Wu et al. 2019; Correia et al. 2020; Shamsuddin et al. 2021; Yujin et al. 2021; Feldmann et al. 2022; Marinelli et al. 2022; Pervez et al. 2022; Wu et al. 2022; Wuni et al. 2022; Agapiou 2022; Tsz Wai et al. 2023	Economic	26	4
B5	Lack of a national standards and design codes for prefabricated components	Anuar et al. 2014; Motiar 2014; Zhai et al. 2014; Zhang et al. 2014; Chao et al. 2015; Luo et al. 2015; Gan et al. 2017, 2019; Li et al. 2017; Xue et al. 2017; Gan et al. 2018a,2018b; Zhang et al. 2018; Jiang et al. 2018; Wu et al. 2019; Dang et al. 2020; Jiang et al. 2020; Li 2020; Zhang and Tsai 2021; Zhang et al. 2022; Ismail et al. 2022; Lan et al. 2022; Navaratnam et al. 2022; Wuni et al.	Political/ Legal Technical	26	4

		2022; Akinradewo et al. 2023; Wuni et al.2023b			
B6	Transportation limitations	Motiar 2014; Zhai et al. 2014; Luo et al. 2015; Gan et al. 2018b; Hwang et al. 2018; Han and Wang 2018; Ji et al. 2018; Zhang et al. 2018; Gan et al. 2018a, 2018b, 2019; Gong et al. 2019; Li 2020; Sooriyamudalige et al. 2020; Wuni and Shen 2020; Gumusburun Ayalp and Ay 2021; Agapiou 2022; Kedir et al. 2022; Lan et al. 2022; Li et al. 2022; Marinelli et al. 2022; Navaratnam et al. 2022; Pervez et al. 2022; Yang et al. 2022; Akinradewo et al. 2023; Tsz Wai et al. 2023	Technical	25	6
B7	Limited facilities and supply chain options/limited manufacturing capacity	Azhar et al. 2013; Anuar et al. 2014; Motiar 2014; Zhai et al. 2014; Zhang et al. 2014; Chao et al. 2015; Li et al. 2017; Xue et al. 2017; Jiang et al. 2018; Gan et al. 2018a, 2018b, 2019; Gumusburun Ayalp and Ay 2021; Agapiou 2022; Kedir et al. 2022; Li et al. 2022; Lopez et al. 2022; Lu et al. 2022; Marinelli et al. 2022; Navaratnam et al. 2022; Pervez et al. 2022; Wuni et al. 2022; Akinradewo et al. 2023; Tsz Wai et al. 2023; Wuni and Shen 2023	Technical	25	7
B8	Resistance to change or innovation, conservative mindset, and risk aversion	Azhar et al. 2013; Shahzad and Mbachu 2013; Anuar et al. 2014; Larsson et al. 2014; Motiar 2014; Zhai et al. 2014; Chao et al. 2015; Luo et al. 2015; Zhang et al. 2018; Akmam Syed Zakaria et al. 2018; Han and Wang 2018; Gan et al. 2018a, 2018b, 2019; Wu et al. 2019; Dou et al. 2019a; Wuni and Shen 2020; Li et al. 2021; Agapiou 2022; Feldmann et al. 2022; Lopez et al. 2022; Marinelli et al. 2022; Pervez et al. 2022; Ribeiro et al. 2022; Tsz Wai et al. 2023	Social	25	7
B9	Lack of regulatory process and policy constraints/immature regulatory system	Larsson et al. 2014; Motiar 2014; Zhang et al. 2014; Chao et al. 2015; Luo et al. 2015; Yunus and Yang 2016; Li et al. 2017; Jiang et al. 2018; Han and Wang 2018; Akmam Syed Zakaria et al. 2018; Ji et al. 2018; Gan et al. 2018a, 2018b, 2019; Wu et al. 2019; Dou et al. 2019a; Dou et al. 2019; Correia et al. 2020; Li 2020; Li et al. 2021; Zhang and Tsai 2021; Kedir et al. 2022; Shang et al. 2022; Wu et al. 2022	Political/ Legal	24	9
B10	Site layout limitations	Azhar et al. 2013; Shahzad and Mbachu 2013; Motiar 2014; Zhai et al. 2014; Luo et al. 2015; Han and Wang 2018; Hong et al. 2018; Hwang et al. 2018; Ji et al. 2018; Zhang et al. 2018; Gan et al. 2018a, 2018b, 2019; Gumusburun Ayalp and Ay 2021; Agapiou 2022; Ismail et al. 2022; Lu et al. 2022;	Technical	20	10

		Marinelli et al. 2022; Akinradewo et al. 2023; Tsz Wai et al. 2023			
B11	Lack of professional management method for OSC in project delivery/management complexity	Mohammed et al. 2012; Luo et al. 2015; Gan et al. 2017, 2018a, 2018b, 2019; Akmam Syed Zakaria et al. 2018; Ali et al. 2018; Jiang et al. 2018; Dang et al. 2020; Li 2020; Li et al. 2021; Zhang et al. 2022; Feldmann et al. 2022; Lan et al. 2022; Li et al. 2022; Wuni et al. 2022; Akinradewo et al. 2023; Tsz Wai et al. 2023	Technical	19	11
B12	Require extensive coordination and scheduling during construction	Mohammed et al. 2012; Shahzad and Mbachu 2013; Anuar et al. 2014; Motiar 2014; Hwang et al. 2018; Ji et al. 2018; Gan et al. 2018a; Li et al. 2019; Gumusburun Ayalp and Ay 2021; Li et al. 2022; Lopez et al. 2022; Pervez et al. 2022; Zhang et al. 2022; Zolghadr et al. 2022; Akinradewo et al. 2023; Tsz Wai et al. 2023; Wuni et al. 2020, 2022, 2023a	Technical	19	11
B13	Lack of awareness and understanding of the potentials of OSC	Mohammed et al. 2012; Yunus and Yang 2016; Akmam Syed Zakaria et al. 2018; Han and Wang 2018; Hwang et al. 2018; Gan et al. 2018a, 2018b, 2019; Wu et al. 2019; Dou et al. 2019a; Jiang et al. 2018, 2020; Sooriyamudalige et al. 2020; Wuni and Shen 2020; Li et al. 2021; Wang et al. 2021; Ribeiro et al. 2022; Li et al. 2023	Social	18	13
B14	No design flexibility/adaptability in late changes	Azhar et al. 2013; Motiar 2014; Zhai et al. 2014; Chao et al. 2015; Luo et al. 2015; Ali et al. 2018; Han and Wang 2018; Hwang et al. 2018; Zhang et al. 2018; Jiang et al. 2020; Li 2020; Feldmann et al. 2022; Lopez et al. 2022; Marinelli et al. 2022; Navaratnam et al. 2022; Pervez et al. 2022; Wuni et al. 2022; Kedir et al. 2022	Technical	18	13
B15	Inadequate/poor quality of prefabricated components	Motiar 2014; Zhai et al. 2014; Zhang et al. 2014; Li et al. 2017; Jiang et al. 2018; Zhang et al. 2018; Gan et al. 2018a, 2018b, 2019; Gumusburun Ayalp and Ay 2021; Ji et al. 2021; Zhang and Tsai 2021; Ismail et al. 2022; Kedir et al. 2022; Yang et al. 2022; Wuni and Shen 2023	Technical	16	15
B16	Insufficient government incentives/financial support	Zhai et al. 2014; Zhang et al. 2014; Chao et al. 2015; Luo et al. 2015; Yunus and Yang 2016; Han and Wang 2018; Akmam Syed Zakaria et al. 2018; Jiang et al. 2018; Zhang et al. 2018; Gan et al. 2019; Correia et al. 2020; Jiang et al. 2020; Li 2020; Wang et al. 2021; Kedir et al. 2022; Marinelli et al. 202	Economic Political/ Legal	16	15
B17	Longer lead times for definite project planning and design phases	Anuar et al. 2014; Motiar 2014; Zhai et al. 2014; Luo et al. 2015; Han and Wang 2018; Zhang et al. 2018; Wuni and Shen	Technical Economic	15	17

		2020; Agapiou 2022; Ismail et al. 2022; Lopez et al. 2022; Ribeiro et al. 2022; Wuni et al. 2022, 2023; Tsz Wai et al. 2023; Wuni and Shen 2023			
B18	Lack of appropriate equipment/technologies in project delivery	Mohammed et al. 2012; Anuar et al. 2014; Motiar 2014; Chao et al. 2015; Luo et al. 2015; Gan et al. 2017; Ji et al. 2018; Nasrun et al. 2019; Wu et al. 2019; Ji et al. 2021; Zhang and Tsai 2021; Ismail et al. 2022; Marinelli et al. 2022; Pervez et al. 2022	Technical	14	18
B19	Unfavourable building regulations	Anuar et al. 2014; Hwang et al. 2018; Gan et al. 2018a, 2018b, 2019; Jiang et al. 2020; Li 2020; Li et al. 2021; Feldmann et al. 2022; Kedir et al. 2022; Marinelli et al. 2022; Wuni et al. 2022; Akinradewo et al. 2023	Political/ Legal Technical	13	19
B20	Unable to achieve economies of scale	Anuar et al. 2014; Chao et al. 2015; Luo et al. 2015; Lee and Kim 2017; Li et al. 2017; Akmam Syed Zakaria et al. 2018; Jiang et al. 2018; Correia et al. 2020; Jiang et al. 2020; Agapiou 2022; Lan et al. 2022; Lopez et al. 2022; Wuni et al. 2022	Economic	13	19
B21	Negative perception and scepticism regarding OSC	Azhar et al. 2013; Motiar 2014; Zhai et al. 2014; Luo et al. 2015; Ali et al. 2018; Gan et al. 2019; Correia et al. 2020; Jiang et al. 2020; Ismail et al. 2022; Kedir et al. 2022; Marinelli et al. 2022; Navaratnam et al. 2022; Pervez et al. 2022	Social	13	19
B22	Require greater clarity, precision, and comprehensive decision making in the early planning	Motiar 2014; Zhai et al. 2014; Akmam Syed Zakaria et al. 2018; Hwang et al. 2018; Ji et al. 2018; Gan et al. 2018b; Correia et al. 2020; Sooriyamudalige et al. 2020; Wuni and Shen 2020; Agapiou 2022; Lopez et al. 2022; Wuni et al. 2023a	Technical	12	22
B23	Restrictive for aesthetic and complex/creative design	Zhai et al. 2014; Ali et al. 2018; Jiang et al. 2018; Zhang et al. 2018; Gan et al. 2018a, 2018b, 2019; Gumusburun Ayalp and Ay 2021; Feldmann et al. 2022; Ismail et al. 2022; Navaratnam et al. 2022	Social Technical	11	23
B24	Lack of market promotion	Mohammed et al. 2012; Motiar 2014; Hong et al. 2018; Wu et al. 2019; Dou et al. 2019a, 2019b; Dang et al. 2020; Li et al. 2021; Wang et al. 2021; Kedir et al. 2022; Ribeiro et al. 2022	Social	11	23
B25	Limited market demand	Motiar 2014; Jiang et al. 2018; Han and Wang 2018; Gan et al. 2018a, 2018b, 2019; Wu et al. 2019; Li 2020; Sooriyamudalige et al. 2020; Feldmann et al. 2022	Social	10	25
B26	Uncertainty regarding performance and quality.	Motiar 2014; Zhai et al. 2014; Luo et al. 2015; Han and Wang 2018;	Social	10	25

		Gumusburun Ayalp and Ay 2021; Li et al. 2021; Agapiou 2022; Feldmann et al. 2022; Ribeiro et al. 2022; Akinradewo et al. 2023			
B27	Insufficient guidance and information about OSC	Zhang et al. 2014; Yunus and Yang 2016; Gan et al. 2017; Han and Wang 2018; Zhang et al. 2018; Sooriyamudalige et al. 2020; Wuni and Shen 2020; Li et al. 2021; Zhang and Tsai 2021	Technical	9	27
B28	Unsuitable procurement mechanisms	Larsson et al. 2014; Akmam Syed Zakaria et al. 2018; Hwang et al. 2018; Sooriyamudalige et al. 2020; Wuni and Shen 2020; Ismail et al. 2022; Lopez et al. 2022; Marinelli et al. 2022; Akinradewo et al. 2023	Technical	9	27
B29	Unsuitable standard contractual terms	Larsson et al. 2014; Gan et al. 2017; Hwang et al. 2018; Correia et al. 2020; Wuni and Shen 2020; Koronaki et al 2021; Zhang and Tsai 2021; Agapiou 2022; Marinelli et al. 2022	Political/ Legal	9	27
B30	Limited research and development (R&D) activity within the industry	Chao et al. 2015; Jiang et al. 2018; Han and Wang 2018; Wu et al. 2019; Dou et al. 2019a; Dang et al. 2020; Wang et al. 2021; Ribeiro et al. 2022	Economic	8	30
B31	Complicated interfaces and conflict with traditional project process	Mohammed et al. 2012; Anuar et al. 2014; Motiar 2014; Han and Wang 2018; Gan et al. 2019; Marinelli et al. 2022; Wuni et al. 2022, 2023a	Technical	8	30
B32	Highly restrictive construction tolerances	Motiar 2014; Zhai et al. 2014; Han and Wang 2018; Li 2020; Ismail et al. 2022; Lopez et al. 2022; Marinelli et al. 2022; Wuni et al. 2022	Technical	8	30
B33	Lack of accreditation and certification of manufacturing method/product	Motiar 2014; Luo et al. 2015; Gan et al. 2017; Han and Wang 2018; Jiang et al. 2020; Agapiou 2022; Ribeiro et al. 2022	Political/ Legal	7	33
B34	Limited variety of standard prefabrication components/ monotony of structure type	Zhai et al. 2014; Chao et al. 2015; Luo et al. 2015; Han and Wang 2018; Gumusburun Ayalp and Ay 2021; Ismail et al. 2022; Zolghadr et al. 2022	Technical Social	7	33
B35	Environmental constraints	Han and Wang 2018; Li et al. 2019; Ji et al. 2021; Jeong et al. 2022; Lopez et al. 2022; Lu et al. 2022	Environmental	6	35
B36	Difficulty in obtaining finance	Anuar et al. 2014; Motiar 2014; Correia et al. 2020; Li 2020; Navaratnam et al. 2022; Akinradewo et al. 2023	Economic	6	35
B37	Supply chain disruptions and disturbances	Lee and Kim 2017; Wuni and Shen 2020; Wuni et al. 2022, 2023a; Wuni and Shen 2023	Technical	5	37
B38	High transportation costs	Motiar 2014; Han and Wang 2018; Hong et al. 2018; Jiang et al. 2020; Li et al. 2021	Economic	5	37

B39	Inappropriate/Lack of well-developed business model	Jiang et al. 2018; Gan et al. 2018a, 2018b, 2019; Akinradewo et al. 2023	Economic	5	37
B40	Project requires bespoke design	Motiar 2014; Hwang et al. 2018; Zhang et al. 2018; Agapiou 2022; Lopez et al. 2022	Technical	5	37
B41	Slower/complex rectification of errors	Lopez et al. 2022; Marinelli et al. 2022; Ribeiro et al. 2022; Wuni et al. 2022	Technical	4	41
B42	Project condition	Akmam Syed Zakaria et al. 2018; Nasrun et al. 2019; Li et al. 2022; Ribeiro et al. 2022	Technical Economic	4	41
B43	Uncertainty of market demand	Chao et al. 2015; Lu et al. 2022; Ribeiro et al. 2022; Shang et al. 2022	Social	4	41
B44	Traditional design process unsuited to OSC	Han and Wang 2018; Wuni and Shen 2020; Wuni et al. 2023b	Technical	3	44
B45	Health and Safety risks and concerns	Jeong et al. 2022; Navaratnam et al. 2022; Akinradewo et al. 2023	Technical	3	44
B46	Lack/ complex of quality assurance and control in project delivery	Dang et al. 2020; Gumusburun Ayalp and Ay 2021	Technical Political/ Legal	2	46
B47	Modular design complexity	Wuni et al. 2022, 2023a	Technical	2	46

3.2 PESTLE Analysis

3.2.1 Political/ legal barriers

Government policies and regulations, usually employing a topdown approach, are central to this category of barriers. Political decisions are vital in shaping the frameworks and regulatory environment for OSC by establishing and enforcing policies, regulations, standards, and guidelines on a broader level. The key political and legal barriers to OSC circumvented a lack of regulatory processes and policy constraints to OSC (B9), and coupled to this, a lack of national standards/design codes for prefabricated components (B5). Both factors were highly cited in the reviewed articles; B9 featured in 24 articles and similarly, B5 featured in 26 articles. These barriers were identified in articles whose research was based primarily in developed nations (Sweden, UK, and Australia), and also China, who cited that OSC requires substantial capital investment, so implementing this approach in projects without sufficient and well-defined regulatory guidance can lead to financial losses– and in countries where gaps in regulation and design standards need to be addressed, such as South Africa and Kenya (Kedir et al. 2022), Malaysia (Anuar et al. 2014), and Nigeria (Akinradewo et al. 2023). For instance, Akmam Syed Zakaria et al. (2018) emphasized that without well-defined rules and regulations regarding standardization, the use of OSC can be very costly. They highlighted that a lack of uniformity in Malaysian building projects significantly impacts design, quality control, and economies of scale. Additionally, Kedir et al. (2022) revealed that many stakeholders in Africa view off-site construction as costly due to expensive construction materials, driven by high import rates. This reliance on imports stems from inadequate regulations and policy constraints, which hinder local manufacturing development and maintain high material costs.

In a similar vein, B19 also identified that there were unfavourable building regulations associated with OSC (Anuar et al. 2014; Hwang et al. 2018; Gan et al. 2018a, 2018b, 2019; Jiang et al. 2020; Li 2020; Li et al. 2021; Feldmann et al. 2022; Kedir et al. 2022; Marinelli et al. 2022; Wuni et al. 2022; Akinradewo et al. 2023), since current policies are not yet fully developed to fill the gaps in the OSC industrial chain, and the adoption impact of OSC has not met the anticipated objectives. Governments must promptly and consistently implement corresponding measures based on market developments to expedite the industry's growth. Nine articles went further and stipulated the issue of unsuitable contractual terms (B29) highlighting their potential to influence the decision-making process regarding the adoption of OSC (Larsson et al. 2014; Gan et al. 2017; Hwang et al. 2018; Correia et al. 2020; Wuni and Shen 2020; Zhang and Tsai 2021; Koronaki et al. 2021; Agapiou 2022; Marinelli et al. 2022). The absence of collaborative contracts, the heightened transfer of risk to contractors, the intricacy of contracts, and the absence of clear definitions of stakeholders' contractual responsibilities, particularly in a relatively novel method/technology like OSC, had an impact on the success of OSC adoption in projects (Correia et al. 2020; Marinelli et al. 2022). Finally, a lack of accreditation/certification of manufacturing method/product (B33), and a lack of quality assurance and control (B46), was also deemed critical to the adoption of OSC. Notably, as OSC has only recently emerged as viable alternatives to more conventional construction methods, such as in China and UK, there is a notable absence of standardization of design, and many pertinent quality assessment tools and accreditations have yet to be established (Motiar 2014).

It can be observed from Figure 6 that political/legal barriers to OSC have always prevailed over the past decade, maintaining a relatively same level of impact, despite the increasing awareness and recognition from both governments and decision makers in the construction industry on the significance of OSC in recent years (Gan et al. 2018a; Oti-Sarpong et al. 2022). This is in addition to several government regulations, policies, and initiatives across the globe promoting the development of OSC and its uptake generally; such as the construction industry development board (2011–2015) OSC roadmap in Malaysia (Yunus and Yang 2016; Akmam Syed Zakaria et al. 2018); transforming infrastructure performance: Roadmap to 2030 in UK (IPA 2021); mandatory adoption of OSC for affordable housing in Chongqing, Beijing, and Shenzhen jurisdictions in China (Gan et al. 2018a); and other various drives from governments globally. Nonetheless, there are still imperfect/inadequate policies, regulations, and orientation, hindering the full and rapid adoption of OSC within the industry. For example, Sweden has been more effective than other regions in promoting increased OSC utilization (Oti-Sarpong et al. 2022). Nevertheless, the challenges of advancing industrialization in infrastructure and commercial construction have impeded the adoption of OSC in these project categories.

This was traced back to the client's role and government to establish regularity processes to promote increased industrialization of both products and processes throughout the value chain (Larsson et al. 2014). In China, despite the presence of certain policy documents aimed at fostering the advancement of OSC, the existing policies fall short of achieving the desired objectives (Zhang et al. 2014; Gan et al. 2018a; Li et al. 2021). According to Li et al. (2021), the government must promptly and consistently implement appropriate measures in response to market developments.

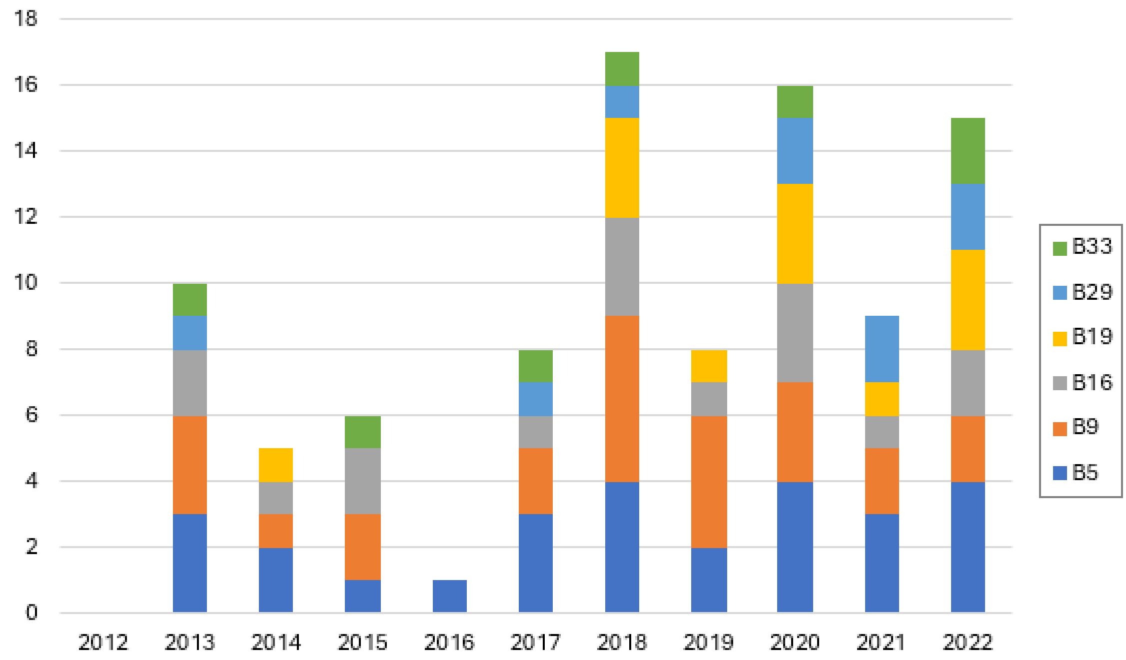

Figure 6: Political/legal OSC related barriers in the reviewed articles by year

3.2.2 Economical barriers

Economic barriers are related to business profitability, emphasizing the advantages of adopting OSC over traditional construction methods and the implementation of more cost-effective solutions. There were a noticeable number of financial barriers identified relating to the increased cost of OSC projects over traditional build projects. These include increased project and capital costs (B3 and B4), and increased transportation costs (B38)—this latter barrier was deemed a priority in the review papers covering China (Motiar 2014; Han and Wang 2018; Hong et al. 2018; Jiang et al. 2020; Li et al. 2021), whereby enterprises still face the obstacles of imperfect logistics systems in the transportation of building components: such as poor planning, long distance, slow confirmation speed of information from stakeholders and the size restrictions of transport components.

B3 was the third ranked barrier, cited in 28 of the articles reviewed, followed immediately by B4 with 26 citations. OSC is proven to be a cost-effective option, leading to potential savings in the lifecycle costs of construction projects (Pan and Sidwell 2011). Nevertheless, if not managed appropriately, OSC can lead to substantial cost overruns, placing a significant financial burden on construction firms. For instance, delays in delivering project components to the construction site may lead to schedule setbacks and extra costs related to equipment and labour hire. This is in addition to potential tower and mobile crane breakdowns that could disrupt the installation process and lead to schedule delays (Luo et al. 2015; Han and Wang 2018; Hong et al. 2018; Navaratnam et al. 2022). The adoption of OSC is often associated with higher initial and capital costs, which depend on the extent of adoption within a given country. Typically, OSC adoption requires large upfront material and overhead costs (e.g. equipment, labours, storage, etc.,) that usually equals up to 60% of a module's total cost (Luo et al. 2015; Salama et al. 2020)—this large upfront capital requirements often results in difficulty in obtaining finance and/or high lending rates from banks (B36; Anuar et al. 2014; Motiar 2014; Correia et al. 2020; Li 2020; Navaratnam et al. 2022; Akinradewo et al. 2023). Further, the limited demand for OSC in certain countries, such as China, Malaysia, Australia, and Korea, delays the realization of economies of scale (B20). This is because it takes manufacturers and suppliers a longer time to reach a break-even point, ultimately resulting in higher prices for OSC components.

Much of the research called for more government incentives/ financial support (B16) for organizations to adopt OSC (16 articles), as it was difficult to obtain finance to support the start-up process of OSC. Government support is essential for the integration of innovative technologies like OSC. Due to the fragmented nature of the construction industry, resistance to innovation, and conservative consumption habits of stakeholders (Blismas and Wakefield 2009; Jiang et al. 2018), the impact of governments on the adoption of OSC is substantial and observable in numerous countries. In Hong Kong, for example, the government offers concessions gross floor area to private developers who incorporate OSC in their projects (Zhang et al. 2018). The Malaysian Construction Industry Development Board (CIDB) initiated an OSC roadmap for 2011–2015 to promote the adoption of this technology (Yunus and Yang 2016; Akmam Syed Zakaria et al. 2018). Similar initiatives have been implemented by other governments, such as in the UK and Australia to promote the application of OSC (Gibb 2001; Blismas and Wakefield 2009; Hwang et al. 2018; Correia et al. 2020). Low levels of R&D (B30) in OSC generally were also raised by this review in 8 articles, stipulating that the current standards and systems in OSC are often not fully developed (Chao et al. 2015; Jiang et al. 2018; Han and Wang 2018; Wu et al. 2019; Dou et al. 2019a; Dang et al. 2020; Wang et al. 2021; Ribeiro et al. 2022). Finally, Figure 7 shows that financial related concerns of OSC have always prevailed over the past decade, maintaining a relatively same level of impact, which has perhaps accounted for its moderate uptake globally.

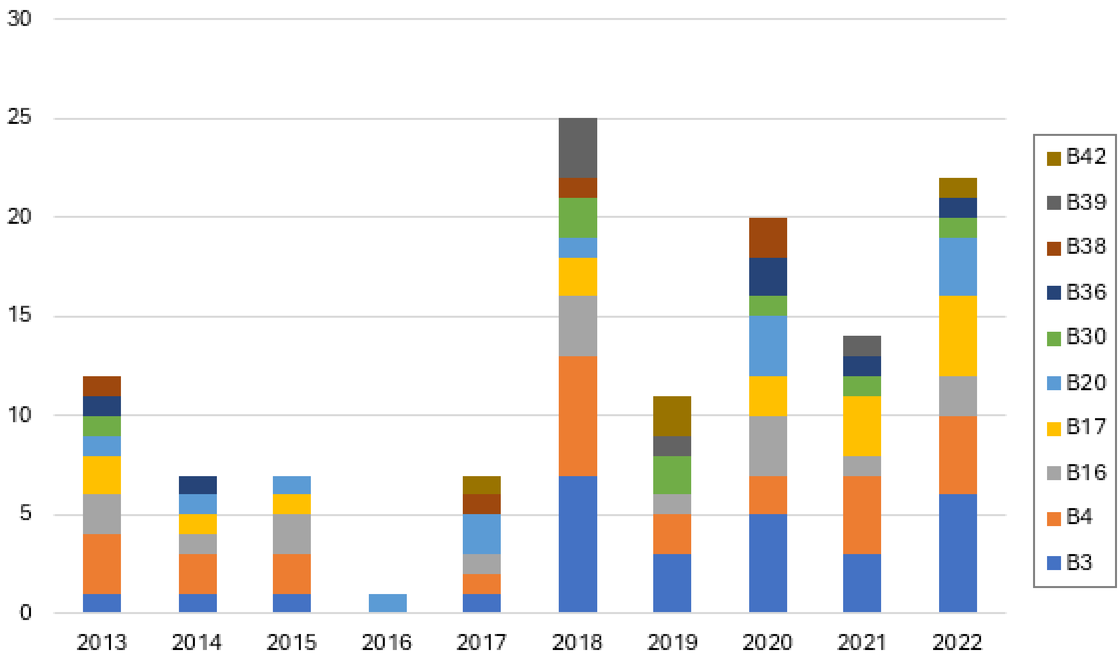

Figure 7: Finance OSC related barriers in the reviewed articles by year

3.2.3 Social barriers

Social barriers relate to cultural and behavioural aspects, encompassing various human factors within the construction industry. Of significance, the highest ranked barrier in this review, B1, related to a lack of skills and expertise of OSC within the organization. This was mentioned in 49 articles (65%) covering research in 15 countries, including UK, China, Australia, Malaysia, India, Germany, New

Zealand, Turkey, Ethiopia, Kenya, South Africa, Portugal, Pakistan, South Korea, and in Nigeria. As an innovative construction method, specialized expertise and skills are essential for the successful implementation of OSC. This is crucial because the level of experience and skills has a direct impact on the performance and quality of OSC projects (Gan et al. 2018b; Marinelli et al. 2022; Akinradewo et al. 2023). For example, based on their experience, stakeholders can optimize specific processes to maximize value for money. Sufficient experience and expertise can lead to more efficient and safer investments by ensuring higher work quality and reducing reworks/defects, ultimately resulting in cost savings for OSC projects.

The second highest barrier cited by 32 articles was poor cooperation and integration between stakeholders (B2), and whilst this covered a lack of technical mechanisms to support communication and collaboration, it was recognized that the industry at large and its stakeholders is central to process. For example, the vertical fragmentation of the construction industry limits the contractor's involvement in decision making earlier in the planning process of the project, preventing the development of plans and proposals for effective application of OSC (Azhar et al. 2013). Notably, resistance to adopting OSC itself (B8) was highly cited, whereby 33.3% of all reviewed articles emphasized the issues of conservatism and risk aversive nature of industry, organizations and individuals. The shift toward digital and environmentally sustainable construction faces challenges related to functionality, formative, and skills, which much of the traditional industry may be hesitant to embrace (Agapiou 2022; Marinelli et al. 2022). In light of this, the implementation of suitable mandatory regulations and policies in the industry becomes critically important and can significantly promote the adoption of OSC.

Similarly, 13 review articles cited that scepticism and a negative perception [B21] in the sector still persists (Azhar et al. 2013; Motiar 2014; Zhai et al. 2014; Luo et al. 2015; Ali et al. 2018; Gan et al. 2019; Correia et al. 2020; Jiang et al. 2020; Ismail et al. 2022; Kedir et al. 2022; Marinelli et al. 2022; Navaratnam et al. 2022; Pervez et al. 2022); with 5 articles resulting from research conducted in China. B23 through to B26 supports this stance, whereby researchers raised that the restrictive nature of design and stifling of creativity is still associated with OSC; lack of market promotion and limited market demand; and uncertainty over quality and performance of OSC projects. Importantly, perhaps B13 surmises this overall social concern, as 24% of all reviewed articles the ongoing issue of insufficient awareness regarding the advantages of OSC, particularly among owners and developers.

As mentioned above, social barriers were considered to cover a range of human factors related to construction stakeholder's attitudes and behaviour toward OSC. Figure 8 illustrates these barriers by published year, it is interesting to note, which is increasing as the number of research in this area has grown over the past decade (as per Figure 2). This aligns with the results of prior behavioural research studies, which has increasingly emphasized the influence of human factors on the construction industry's performance. For example, Alhawamdeh and Lee (2021) contended that the prevailing causes of construction waste generation are either directly or indirectly influenced by the attitudes of construction stakeholders. Consequently, a negative attitude could lead to a substantial increase in waste generation. Similarly, Famiyeh et al. (2017) revealed that the attitude of client, consultant, and the contractor can largely affect the cost of construction projects. In the OSC context, several papers in this review have emphasized the critical role of construction stakeholders' behaviour and attitude towards the success of OSC adoption in the sector (Luo et al. 2015; Li et al. 2017; Wang et al. 2021).

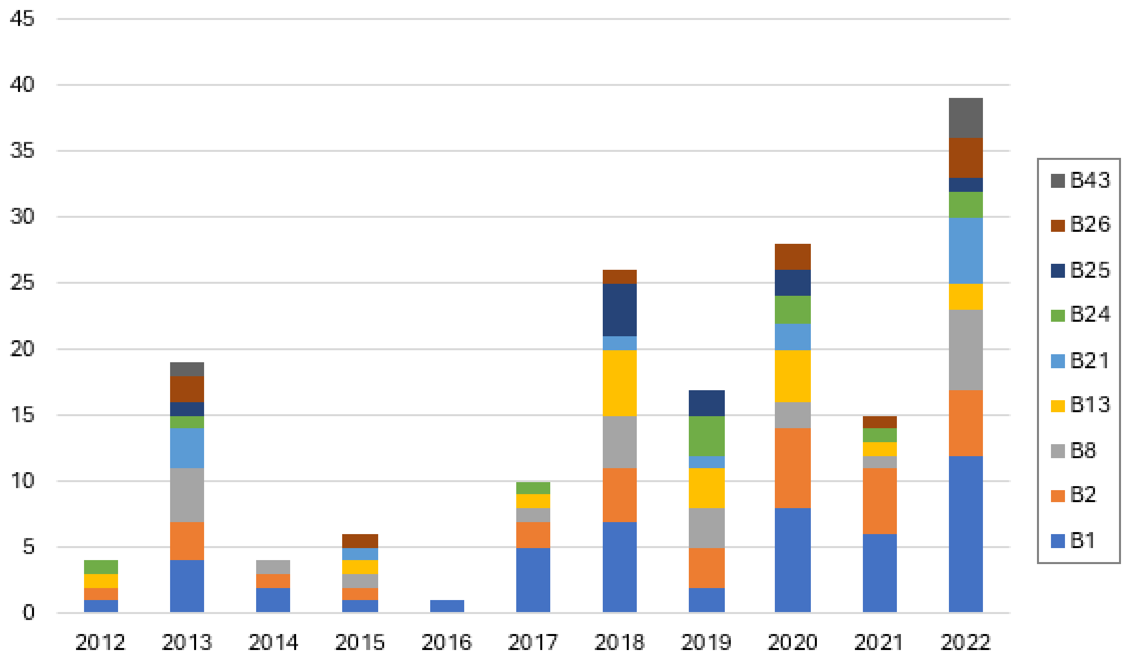

Figure 8: Behavioural and attitudinal OSC related barriers in the reviewed articles by year

3.2.4 Technical barriers

Technical barriers involve the availability of infrastructure, procedures, and tools for the implementation of OSC. This is in addition to aspects related to the adoption of advanced and innovative technology solutions in design and standardization. The technical barriers cover more than half of all the barriers identified in this review (57%), which indicate their significance in relation to acceptance and adoption of OSC. They can be divided into those that relate to the design of OSC (B5, B14, B23, B34, B40, B41, B44, B47), the resulting 'product' of OSC (B15, B31, B32, B42), and the process of OSC (B2, B6, B7, B10, B11, B12, B17, B18, B19, B22, B27, B28, B37, B45, B46). The highest ranked (most frequent) design barrier was the lack of national standards and design codes for prefabricated components (B5) and was featured in 26 of the reviewed articles; followed by the lack of flexibility and adaptability for late design changes (B14) which was cited in 18 articles. Building standards and codes serve as the regulatory framework that guarantee projects are planned, designed, and constructed in compliance with various prerequisites encompassing aspects like structural integrity, durability, indoor environmental quality, sustainability, energy efficiency, comfort, and zoning regulations. Given the dissimilarities in engineering between OSC and traditional construction, the design standards and codes that apply to the latter are not applicable to the former. Considering that OSC is still in its early stages of development in numerous countries, particularly in developing nations, and given the substantial capital investment required, implementing this approach in projects lacking adequate and well-defined regulatory guidance could lead to financial losses (Luo et al. 2015).

In terms of OSC product related barriers, the poor quality of prefabricated components (B15) featured as a result of an underperformance of building components. OSC is anticipated to enhance quality assurance and control by enabling the execution of production and construction processes within a more controlled environment, thereby reducing defects, uncertainties, and interruptions in both component production and onsite activities. However, scepticism persists regarding this approach due to negative experiences, including instances of subpar OSC performance resulting in issues, such as low building quality, leaks, and architectural monotony (Zhang et al. 2014; Ismail et al. 2022). Furthermore, given the higher quality standards expected for manufactured building components, shortcomings in manufacturer skills and insufficient investment in research and development (R&D) can also pose practical challenges (Ismail et al. 2022; Li et al. 2023). The highly restrictive tolerances associated with OSC (B32) is another important product related barrier, cited in 8 articles. In OSC projects there is virtually no room for design errors because the schedule of production becomes fixed once it commences (Motiar 2014; Han and Wang 2018). Design defects can lead to significant geometric and dimensional disparities between manufacturing and assembly tolerances, potentially resulting in construction defects that necessitate costly rectifications and rework (Wuni et al. 2022). Furthermore, incorporating changes to project scope in OSC is challenging due to limited flexibility in accommodating late design alterations and complex interfaces with traditional project processes (B31; Mohammed et al. 2012; Anuar et al. 2014; Motiar 2014; Han and Wang 2018; Gan et al. 2019; Marinelli et al. 2022; Wuni et al. 2022, 2023a).

The vast majority of technical related barriers were found to be process related, these include primary process related barriers such poor cooperation and integration between stakeholders (B2), transport limitations (B6), limited facilities and supply chain options (B7), and site layout (B10). In terms of cooperation between multi-interfaces, as previously mentioned, the successful integration of the OSC supply chain relies on efficient communication and the exchange of information. Design information gap between manufacturer and designer, inadequate design data transition, and logistics information inconsistency may result in significant time delays, considering the shorter schedules in OSC projects and the increased hourly rental for assembly equipment (Wuni et al. 2022; Wuni and Shen 2023). Transport limitations were also noted as a deep concern that may impact the decision of clients/developers to adopt OSC— this was prevalent from research undertaken in most countries in this review. This is due to logistical constraints, such as size of OSC modules and components, logistical timing of transportation, cost, transport route, etc. For example, in India, the unequal distribution of rural and urban areas across the nation, deficient transport infrastructure, and restricted accessibility to specific sites, including construction locations, were recognized as factors that heightened the intricacy and challenges associated with efficiently transporting high-density modules (Marinelli et al. 2022). Furthermore, the constrained availability of facilities and supply chain alternatives can lead to lengthy transportation distances, making it often quite intricate to plan and ascertain the most practical route in terms of both time and cost to the project (Gan et al. 2018a, 2018b; Marinelli et al. 2022).

3.2.5 Environmental barriers

There was only one environmental barrier identified, which is to be expected given that OSC, by its very nature, was conceded to address several environmental factors over traditional build methods, such as reduction in construction waste due to poor workmanship and onsite storage; reduction in carbon emissions associated to regular delivery onsite of materials and equipment, and site operative travel to the construction site, etc. However, in this review, few studies have raised concerns over the impact of the environment on OSC projects (Han and Wang 2018; Li et al. 2019; Ji et al. 2021; Jeong et al. 2022; Lopez et al. 2022; Lu et al. 2022). An overarching environmental constraint (B35) was employed to characterize barriers associated with external natural environmental risks, such as severe or unforeseen adverse weather conditions, earthquakes, fires, and so forth, which can influence personnel, materials, and machinery involved in the construction process. For example, high temperatures or heat stress experienced during the summer in some countries can hinder the progress of OSC projects or reduce workers’ productivity, thus impacting the installation rate (Li et al. 2019).

4. Conclusion

The benefits of OSC have been widely acknowledged by governments, yet uptake by construction stakeholders globally has been modest. This paper presented a structured review and meta-synthesis of drivers to support OSC adoption in the construction industry. A total of 75 scientific articles were selected corresponding to the period 2012–2022 and covering a range of countries from 5 continents namely Europe, Oceania, Asia, North America, and Africa. The annual publications trend showed a growing interest in this matter, with a noticeable rise in the last 5 years with 25.3% of articles published in 2022 alone.

More than half of the articles reviewed were from Asia (61%), with China and Malaysia being the most prolific countries. On the other hand, there was an absence of representation from South America and very few articles published in North America and Africa which suggests a lack of priority for implementing the OSC method in these continents. The reviewed article's project types were mainly related to construction generally and housing construction, with little focus on infrastructure and commercial projects. A total of 47 barriers were identified through this review and were classified and grouped according to PESTLE analysis (Political, Economic, Social, Technical, Legal, and Environmental). The most frequent barrier within each category were:

1. Lack of a national standards and design codes for prefabricated components (political/legal)
2. Higher project costs (economic)
3. Lack of skills and expertise in OSC within the organisation (social)
4. Poor cooperation and integration between stakeholders in the value chain (technical)
5. Environmental constraints (Environmental)

It was noted that technical barriers involving the design, the resulting 'product', and the process of OSC had the largest impact on the successful and effective adoption of OSC in projects. Indeed, logistical constraints, uncertainties, and risks associated with the design and process of OSC can have a significant impact on the performance and final outcome of the project. Social was the second most important category which emphasized the critical role of construction stakeholders' behaviour and attitude towards the success of OSC adoption in the sector. Several significant barriers were also identified under both economical and political/legal categories, however, little concern was put on the environmental barriers, which can be attributed to the fact that the nature of OSC was conceded to address several environmental factors over traditional build methods.

To overcome barriers to OSC adoption, it is crucial to enhance skills through targeted education and training programs, thereby improving technical and managerial expertise. Effective stakeholder cooperation can be achieved by implementing collaborative frameworks and advanced technologies like BIM. Additionally, offering tailored financial support mechanisms, such as bank loans, subsidies, and public-private partnerships, is essential. Establishing comprehensive national standards and design codes through industry collaboration will ensure quality and consistency. Furthermore, incentivizing construction stakeholders with tax breaks and expedited permitting processes can streamline adoption. Increasing awareness through campaigns and showcasing successful case studies will shift perceptions and encourage broader acceptance. While these recommendations address critical issues, future research can explore additional strategies to promote the adoption of OSC.

It is recognized that a limitation of this study is the number of citation databases used in this systematic review. Extending sources could potentially identify differing barriers and ensure a greater number of articles are sourced to reflect an improved country analysis. Meanwhile, future research can also build upon the findings of this paper to investigate and articulate the causative factors underlying the persistence of the identified OSC barriers.

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References

Agapiou A. 2022. Barriers to offsite construction adoption: a quantitative study among housing associations in England. Buildings. 12(3):283. doi: 10.3390/buildings12030283.

Akinradewo O, Aigbavboa C, Aghimien D, Oke A, Ogunbayo B. 2023. Modular method of construction in developing countries: the underlying challenges. Int J Constr Manage. 23(8):1344–1354. doi: 10.1080/15623599. 2021.1970300.

Akmam Syed Zakaria S, Gajendran T, Skitmore M, Brewer G. 2018. Key factors influencing the decision to adopt industrialised building systems technology in the Malaysian construction industry: an inter-project perspective. Archit Eng Des Manage. 14(1–2):27–45. doi: 10.1080/ 17452007.2017.1298512.

Alhawamdeh M, Lee A. 2021. A behavioral framework for construction waste minimization : the case of Jordan. Int J Environ Sustain. 17(2):9–32. doi: 10.18848/2325-1077/CGP/v17i02/9-32.

Ali MM, Abas NH, Affandi HM, Abas NA. 2018. Factors impeding the industrialized building system (IBS) implementation of building construction in Malaysia. Int J Eng Technol. 7(4):2209–2212.

Anuar K, Kamar M, Nor M, Azman A, Nasrun M, Nawi M. 2014. IBS Survey 2010: drivers, barriers and critical success factors in adopting industrialised building system (IBS) construction by G7 contractors in Malaysia. J Eng Sci Technol. 9(4):490–501.

Azhar S, Lukkad MY, Ahmad I. 2013. An investigation of critical factors and constraints for selecting modular construction over conventional stickbuilt technique. Int J Constr Educ Res. 9(3):203–225. doi: 10.1080/ 15578771.2012.723115.

Blismas N, Wakefield R. 2009. Drivers, constraints and the future of offsite manufacture in Australia. Constr Innov. 9(1):72–83. doi: 10.1108/ 14714170910931552.

Chao M, Qiping S, Wei P, Kunhui Y. 2015. Major barriers to off-site construction: the developer's perspective in China. J Manage Eng. 31(3): 04014043. doi: 10.1061/(ASCE)ME.1943-5479.0000246.

Correia JM, Sutrisna M, Zaman AU. 2020. Factors influencing the implementation of off-site manufacturing in commercial projects in Western Australia: a proposed research agenda. J Eng Des Technol. 18(6):1449– 1468. doi: 10.1108/JEDT-09-2019-0246.

Dang P, Niu Z, Gao S, Hou L, Zhang G. 2020. Critical factors influencing the sustainable construction capability in prefabrication of Chinese construction enterprises. Sustainability. 12(21):8996. doi: 10.3390/su12218996.

Dou Y, Xue X, Zhao Z, Jiang Y. 2019a. Measuring the factors that influence the diffusion of prefabricated construction technology innovation. KSCE J Civ Eng. 23(9):3737–3752. doi: 10.1007/s12205-019-2029-3.

Dou Y, Xue X, Zhao Z, Luo X. 2019b. Factors influence China's off-site construction technology innovation diffusion. Sustainability. 11(7):1849. doi: 10.3390/su11071849.

Elnaas E. 2014. The decision to use off-site manufacturing (OSM). In: Systems for house building projects in the UK. Brighton, UK: University of Brighton.

Famiyeh S, Amoatey CT, Adaku E, Agbenohevi CS. 2017. Major causes of construction time and cost overruns: a case of selected educational sector projects in Ghana. J Eng Des Technol. 15(2):181–198. doi: 10.1108/JEDT11-2015-0075.

Feldmann FG, Birkel H, Hartmann E. 2022. Exploring barriers towards modular construction – a developer perspective using fuzzy DEMATEL. J Clean Prod. 367:133023. doi: 10.1016/j.jclepro.2022.133023.

Gan X, Chang R, Wen T. 2018b. Overcoming barriers to off-site construction through engaging stakeholders: a two-mode social network analysis. J Clean Prod. 201:735–747. doi: 10.1016/j.jclepro.2018.07.299.

Gan X, Chang R, Zuo J, Wen T, Zillante G. 2018a. Barriers to the transition towards off-site construction in China: an Interpretive structural modeling approach. J Clean Prod. 197:8–18. doi: 10.1016/j.jclepro.2018.06.184.

Gan XL, Chang RD, Langston C, Wen T. 2019. Exploring the interactions among factors impeding the diffusion of prefabricated building technologies: fuzzy cognitive maps. Eng Constr Archit Manage. 26(3):535–553. doi: 10.1108/ECAM-05-2018-0198.

Gan Y, Shen L, Chen J, Tam VWY, Tan Y, Illankoon IMCS. 2017. Critical factors affecting the quality of industrialized building system projects in China. Sustainability. 9(2):216. doi: 10.3390/su9020216.

Gibb AGF. 2001. Standardization and pre-assembly-distinguishing myth from reality using case study research. Constr Manage Econ. 19(3):307–315. doi: 10.1080/01446190010020435

Gong P, Teng Y, Li X, Luo L. 2019. Modeling constraints for the on-site assembly process of prefabrication housing production: a social network analysis. Sustainability. 11(5):1387. doi: 10.3390/su11051387.

Goodier C, Gibb A. 2007. Future opportunities for offsite in the UK. Constr Manage Econ. 25(6):585–595. doi: 10.1080/01446190601071821.

Gumusburun Ayalp G, Ay I. 2021. Model validation of factors limiting the use of prefabricated construction systems in Turkey. Eng Constr Archit Manage. 28(9):2610–2636. doi: 10.1108/ECAM-04-2020-0248.

Han Y, Wang L. 2018. Identifying barriers to off-site construction using grey DEMATEL approach: case of China. J Civ Eng Manage. 24(5):364–377. doi: 10.3846/jcem.2018.5181.

Hong J, Shen GQ, Li Z, Zhang B, Zhang W. 2018. Barriers to promoting prefabricated construction in China: a cost–benefit analysis. J Clean Prod. 172:649–660. doi: 10.1016/j.jclepro.2017.10.171.

Hwang BG, Shan M, Looi KY. 2018. Key constraints and mitigation strategies for prefabricated prefinished volumetric construction. J Clean Prod. 183: 183–193. doi: 10.1016/j.jclepro.2018.02.136.

IPA. 2021. Transforming infrastructure performance: roadmap to 2030. [accessed 2023 Sep 20]. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1016726/IPA_TIP_ Roadmap_to_2030_v6__1_.pdf.

Ismail S, Hon CKH, Crowther P, Skitmore M, Lamari F. 2022. The drivers and challenges of adopting the Malaysia industrialised building system for sustainable infrastructure development. Constr Innov. 23(5):1054–1074. doi: 10.1108/CI-05-2021-0088.

Jansen Van Vuuren T, Middleton C. 2020. Methodology for quantifying the benefits of off-site construction. [accessed 2023 Sep 18]. https://www. repository.cam.ac.uk/handle/1810/317071.

Jeong G, Kim H, Lee HS, Park M, Hyun H. 2022. Analysis of safety risk factors of modular construction to identify accident trends. J Asian Archit Build Eng. 21(3):1040–1052. doi: 10.1080/13467581.2021.1877141.

Ji Y, Qi L, Liu Y, Liu X, Li HX, Li Y. 2018. Assessing and prioritising delay factors of prefabricated concrete building projects in China. Appl Sci. 8(11):2324. doi: 10.3390/app8112324.

Ji Y, Zhao Z, Yao F, Li HX, Li Y, Du X. 2021. Factors influencing sleeve grouting quality for prefabricated building: an interpretive structural modeling approach. Adv Civ Eng. 2021:5598424. doi: 10.1155/2021/5598424.

Jiang L, Li Z, Li L, Gao Y. 2018. Constraints on the promotion of prefabricated construction in China. Sustainability. 10(7):2516. doi: 10.3390/ su10072516.

Jiang W, Huang Z, Peng Y, Fang Y, Cao Y. 2020. Factors affecting prefabricated construction promotion in China: a structural equation modeling approach. PLOS One. 15(1):e0227787. doi: 10.1371/journal.pone.0227787.

Jin R, Hong J, Zuo J. 2020. Environmental performance of off-site constructed facilities: a critical review. Energy Build. 207:109567. doi: 10.1016/ j.enbuild.2019.109567.

Kedir F, Chen Q, Hall DM, Adey BT, Boyd R. 2022. Formative scenario analysis of the factors influencing the adoption of industrialised construction in countries with high housing demand – the cases of Ethiopia, Kenya, and South Africa. Constr Manage Econ. 40(9):690–710. doi: 10.1080/ 01446193.2022.2098508.

Koronaki A, Bukauskas A, Jalia A, Shah DU, Ramage MH. 2021. Prefabricated engineered timber schools in the United Kingdom: challenges and opportunities. Sustainability. 13(22):12864. doi: 10.3390/ su132212864.

Lan L, Xia W, Jingke H, Guangdong W. 2022. Fuzzy cognitive map-enabled approach for investigating the relationship between influencing factors and prefabricated building cost considering dynamic interactions. J Constr Eng Manag. 148(9):04022081. doi: 10.1061/(ASCE)CO.1943-7862.0002336.

Larsson J, Eriksson PE, Olofsson T, Simonsson P. 2014. Industrialized construction in the Swedish infrastructure sector: core elements and barriers. Constr Manage Econ. 32(1–2):83–96. doi: 10.1080/01446193.2013.833666.

Lee JS, Kim YS. 2017. Analysis of cost-increasing risk factors in modular construction in Korea using FMEA. KSCE J Civ Eng. 21(6):1999–2010. doi: 10.1007/s12205-016-0194-1.

Levy Y, Ellis TJ. 2006. A systems approach to conduct an effective literature review in support of information systems research. Inform Sci J. 9:181–212.

Li D, Li X, Feng H, Wang Y, Fan S. 2022. ISM-based relationship among critical factors that affect the choice of prefabricated concrete buildings in China. Int J Constr Manage. 22(6):977–992. doi: 10.1080/15623599.2019. 1675306

Li T, Li Z, Dou Y. 2023. Diffusion prediction of prefabricated construction technology under multi-factor coupling. Build Res Inform. 51(3):333–353. doi: 10.1080/09613218.2022.2126343.

Li X, Li Z, Wu G. 2017. Modular and offsite construction of piping: current barriers and route. Appl Sci. 7(6):547. doi: 10.3390/app7060547.

Li X, Wu C, Wu P, Xiang L, Shen GQ, Vick S, Li CZ. 2019. SWP-enabled constraints modeling for on-site assembly process of prefabrication housing production. J Clean Prod. 239:117991. doi: 10.1016/j.jclepro.2019. 117991.

Li XJ. 2020. Research on investment risk influence factors of prefabricated building projects. J Civ Eng Manage. 26(7):599–613. doi: 10.3846/jcem. 2020.12917.

Li Z, Zhang S, Meng Q, Hu X. 2021. Barriers to the development of prefabricated buildings in China: a news coverage analysis. Eng Constr Archit Manage. 28(10):2884–2903. doi: 10.1108/ECAM-03-2020-0195.

Lopez R, Chong HY, Pereira C. 2022. Obstacles preventing the off-site prefabrication of timber and MEP services: qualitative analyses from builders and suppliers in Australia. Buildings. 12(7):1044. doi: 10.3390/ buildings12071044.

Lu J, Wang J, Song Y, Yuan C, He J, Chen Z. 2022. Influencing factors analysis of supply chain resilience of prefabricated buildings based on PFDEMATEL-ISM. Buildings. 12(10):1595. doi: 10.3390/buildings12101595.

Luo L, Mao C, Shen L, Li Z. 2015. Risk factors affecting practitioners' attitudes toward the implementation of an industrialized building system: a case study from China. Eng Constr Archit Manage. 22(6):622–643. doi: 10.1108/ECAM-04-2014-0048.

Marinelli M, Konanahalli A, Dwarapudi R, Janardhanan M. 2022. Assessment of barriers and strategies for the enhancement of off-site construction in India: an ISM approach. Sustainability. 14(11):6595. doi: 10. 3390/su14116595.

Mohammed A, Jack G, Pour RF. 2012. Promoting off-site construction: future challenges and opportunities. J Archit Eng. 18(2):75–78. doi: 10. 1061/(ASCE)AE.1943-5568.0000081.

Motiar RM. 2014. Barriers of implementing modern methods of construction. J Manage Eng. 30(1):69–77. doi: 10.1061/(ASCE)ME.1943-5479.0000173.

Nadim W. 2012. Modern methods of construction. In: Akintoye A, Goulding JS, Zawdie G, editors. Construction innovation and process improvement. Iowa, USA: Blackwell Publishing; p. 209–223.

Nasrun M, Nawi M, Noordin A, Tamrin N, Akmar F, Nifa A, et al. 2019. An ecological study on enhancing the Malaysian construction ecosystem: readiness implementation factors in industrialised building system (IBS) projects. Ekoloji. 28(107):545–552.

Navaratnam S, Satheeskumar A, Zhang G, Nguyen K, Venkatesan S, Poologanathan K. 2022. The challenges confronting the growth of sustainable prefabricated building construction in Australia: construction industry views. J Build Eng. 48:103935. doi: 10.1016/j.jobe.2021.103935.

Oti-Sarpong K, Shojaei RS, Dakhli Z, Burgess G, Zaki M. 2022. How countries achieve greater use of offsite manufacturing to build new housing: identifying typologies through institutional theory. Sustain Cities Soc. 76: 103403. doi: 10.1016/j.scs.2021.103403.

Pan W, Sidwell R. 2011. Demystifying the cost barriers to offsite construction in the UK. Constr Manage Econ. 29(11):1081–1099. doi: 10.1080/ 01446193.2011.637938.

Pervez H, Ali Y, Pamucar D, Garai-Fodor M, Csisz�arik-Kocsir A. � 2022. Evaluation of critical risk factors in the implementation of modular construction. PLOS One. 17(8):e0272448. doi: 10.1371/journal.pone.0272448.

Peters MD, Godfrey CM, Khalil H, McInerney P, Parker D, Soares CB. 2015. Guidance for conducting systematic scoping reviews. Int J Evid Based Healthc. 13(3):141–146. doi: 10.1097/XEB.0000000000000050.

Ribeiro AM, Arantes A, Cruz CO. 2022. Barriers to the adoption of modular construction in Portugal: an interpretive structural modeling approach. Buildings. 12(10):1509. doi: 10.3390/buildings12101509.

Salama T, Figgess G, Elsharawy M, El-Sokkary H. 2020. Financial modeling for modular and offsite construction. ISARC Proceedings of the International Symposium on Automation and Robotics in Construction; Vol. 37; p. 1082–1089.

Shahzad WM, Mbachu J. 2013. Prefabrication as an onsite productivity enhancer: analysis of impact levels of the underlying constraints and improvement measures in New Zealand construction industry. Int J Project Organ Manage. 5(4):334–354. doi: 10.1504/IJPOM.2013.058382.

Shamsuddin SM, Zakaria R, Abidin NI, Hashim N, Yusuwan NM. 2021. Confirmatory factor analysis of the life cycle costing sub-cost distribution for industrialised building system using SEM-PLS. Eng J. 25(1):287–296. doi: 10.4186/ej.2021.25.1.287.

Shang Z, Wang F, Yang X. 2022. The efficiency of the chinese prefabricated building industry and its influencing factors: an empirical study. Sustainability. 14(17):10695. doi: 10.3390/su141710695.

Singh VK, Singh P, Karmakar M, Leta J, Mayr P. 2021. The journal coverage of Web of Science, Scopus and Dimensions: a comparative analysis. Scientometrics. 126(6):5113–5142. Jundoi: 10.1007/s11192-021-03948-5.

Sooriyamudalige N, Domingo N, Shahzad W, Childerhouse P. 2020. Barriers and enablers for supply chain integration in prefabricated elements manufacturing in New Zealand. Int J Constr Supply Chain Manage. 10(1):73– 91. doi: 10.14424/ijcscm100120-73-91.

Steinhardt Dale A, Manley K. 2016. Adoption of prefabricated housing–the role of country context. Sustain Cities Soc. 22:126–135. doi: 10.1016/j.scs. 2016.02.008.

Thajudeen S, Lennartsson M, Elgh F. 2022. Identification of challenges and success factors in industrialised house building design. Proc Inst Civ Eng. 175(1):27–37. doi: 10.1680/jmapl.20.00011.

Tsz Wai C, Wai Yi P, Ibrahim Olanrewaju O, Abdelmageed S, Hussein M, Tariq S, Zayed T. 2023. A critical analysis of benefits and challenges of implementing modular integrated construction. Int J Constr Manage. 23(4):656–668. doi: 10.1080/15623599.2021.1907525.

van Egmond E. 2012. Innovation, technology and knowledge transfer for sustainable construction. In: Construction innovation and process improvement. Hoboken, NJ, USA: Blackwell Publishing; p. 95–123. doi: 10.1002/ 9781118280294.ch5.

Wang Y, Wang F, Sang P, Song H. 2021. Analysing factors affecting developers' behaviour towards the adoption of prefabricated buildings in China. Environ Dev Sustain. 23(10):14245–14263. doi: 10.1007/s10668-021-01265-8.

Wu G, Yang R, Li L, Bi X, Liu B, Li S, Zhou S. 2019. Factors influencing the application of prefabricated construction in China: from perspectives of technology promotion and cleaner production. J Clean Prod. 219:753–762. doi: 10.1016/j.jclepro.2019.02.110.

Wu H, Qian QK, Straub A, Visscher HJ. 2022. Factors influencing transaction costs of prefabricated housing projects in China: developers' perspective. Eng Constr Archit Manage. 29(1):476–501. doi: 10.1108/ECAM-07-2020- 0506.

Wuni IY, Shen GQ, Antwi-Afari MF. 2023b. Exploring the design risk factors for modular integrated construction projects. Constr Innov. 23(1):213– 228. doi: 10.1108/CI-02-2021-0025.

Wuni IY, Shen GQ, Osei-Kyei R, Agyeman-Yeboah S. 2022. Modelling the critical risk factors for modular integrated construction projects. Int J Constr Manage. 22(11):2013–2026. doi: 10.1080/15623599.2020.1763049.

Wuni IY, Shen GQ, Saka AB. 2023a. Computing the severities of critical onsite assembly risk factors for modular integrated construction projects. Eng Constr Archit Manage. 30(5):1864–1882. doi: 10.1108/ECAM-07-2021-0630.

Wuni IY, Shen GQ. 2020. Fuzzy modelling of the critical failure factors for modular integrated construction projects. J Clean Prod. 264:121595. doi: 10.1016/j.jclepro.2020.121595.

Wuni IY, Shen GQ. 2023. Exploring the critical production risk factors for modular integrated construction projects. J Facil Manage. 21(1):50–68. doi: 10.1108/JFM-03-2021-0029.

Xue H, Zhang S, Su Y, Wu Z. 2017. Factors affecting the capital cost of prefabrication—a case study of China. Sustainability. 9(9):1512. doi: 10.3390/ su9091512.

Xue H, Zhang S, Su Y, Wu Z. 2018. Capital cost optimization for prefabrication: a factor analysis evaluation model. Sustainability. 10(1):159. doi: 10. 3390/su10010159.

Yang S, Hou Z, Chen H. 2022. Network model analysis of quality control factors of prefabricated buildings based on the complex network theory. Buildings. 12(11):1874. doi: 10.3390/buildings12111874.

Yuan Z, Ni G, Wang L, Qiao Y, Sun C, Xu N, Wang W. 2020. Research on the barrier analysis and strength measurement of a prefabricated building design. Sustainability. 12(7):2994. doi: 10.3390/su12072994.

Yujin L, In KJ, Atul K, Martin F. 2021. Empirical study of identifying logistical problems in prefabricated interior wall panel construction. J Manage Eng. 37(3):05021002. doi: 10.1061/(ASCE)ME.1943-5479.0000907.

Yunus R, Yang J. 2016. Legislative challenge to sustainable application of industrialized building system (IBS). J Teknol. 78(5):45–55.

Zhai X, Reed R, Mills A. 2014. Factors impeding the offsite production of housing construction in China: an investigation of current practice. Constr Manage Econ. 32(1–2):40–52. doi: 10.1080/01446193.2013.787491.

Zhang K, Tsai JS. 2021. Identification of critical factors influencing prefabricated construction quality and their mutual relationship. Sustainability. 13(19):11081. doi: 10.3390/su131911081.

Zhang S, Li Z, Ma S, Li L, Yuan M. 2022. Critical factors influencing interface management of prefabricated building projects: evidence from China. Sustainability. 14(9):5418. doi: 10.3390/su14095418.

Zhang W, Lee MW, Jaillon L, Poon CS. 2018. The hindrance to using prefabrication in Hong Kong's building industry. J Clean Prod. 204:70–81. doi: 10.1016/j.jclepro.2018.08.190.

Zhang X, Skitmore M, Peng Y. 2014. Exploring the challenges to industrialized residential building in China. Habitat Int. 41:176–184. doi: 10.1016/j. habitatint.2013.08.005.

Zolghadr A, Gharaie E, Naderpajouh N. 2022. Barriers to innovation in the housing sector: economic justifiability of offsite construction for housebuilders. J Build Eng. 52:104490. doi: 10.1016/j.jobe.2022.104490.