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An offsite construction scoping study for occupational health and safety

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Abstract. Within the sustainable construction philosophical worldview, the construction industry is transiting towards adoption of offsite construction (OSC) as a sine qua non for resolving ill-performances of construction industry. However, its various definitions have potential to obtuse its industry wide benefits and challenges. The aim of this paper is to give a concise description of OSC and its benefits for improving occupation health and safety (OHS). With a framework for conducting a scoping study, this paper highlights various appellations of OSC using scholarly articles by various researchers and practitioners from 2000 to 2020, collected from multiple sources, i.e., Google Scholar and ScienceDirect. The scholarly articles are reviewed regarding research contribution and methodology used. A plethora of OSC studies with divergent scopes and objectives highlight its benefits to environmental sustainability indicators of energy consumption, waste generation and carbon gas emissions, with only implied link to OHS. A new OSC focus that is explicit on OHS benefits and challenges is suggested for future research. The paper contributes to the body of offsite literature by providing a broader OSC definition and reviewing the benefits of OSC to OHS based on their production systems.

1. Introduction

The evolution of the business world is generating significant threats to a sustainable construction sector. Business organisations are facing rapid increase in market globalisation and competition, fluctuating clients' demands and product characteristics, as well as complex global network of supply chain [1]. The construction industry has not been spared from the wave, especially having been historically labelled inefficient and unproductive. The seminal reports [2,3] faulted the construction industry for lack of efficiency and productivity, cost and time overruns, poor quality, minimal profits and poor occupational health and safety (OHS) performance. These ill-performances are compounded by the nature of the construction industry which is highly fragmented with complex contractual agreements, complicated building standards, low levels of investment in research and development, and perpetual diminishing of skilled labour force [3]. In the modern construction age, offsite construction (OSC) has been recognized as a sine qou non to the ill-performances of the construction industry. The main purpose of OSC is to move onsite construction related activities to offsite, i.e., into a controlled manufacturing facility [4]. This approach is said to have several benefits including certainty and predictability of cost of construction; reduced whole lifecycle cost; time schedule savings; improved quality, productivity, sustainability and environmental performance; reduced construction waste and improved OHS performance [4,5]. The OSC experiences in United Kingdom, Unites States, China, Australia, Malaysia and Singapore show that OSC is a timely solution to a wide array of ill-performances of the construction industry. A number of reports have been authored in support of OSC, including Never waste a good crisis, Review of the UK Construction Labour Model: Modernise or Die and Construction 2025 agenda.

In the last two decades, uptake of OSC has accelerated largely due to its benefits to OHS performance. OHS has been defined as "a discipline dealing with the prevention of work-related injuries and diseases as well as the protection and promotion of the health of workers " [6 p1]. OHS is aimed at improving the conditions and factors that affect the health and safety of employees, workers or any other person within the vicinity of the workplace and beyond. Poor OHS has severe consequences on social-economic performance of construction enterprises. When accidents occur, workers may experience fatal and non-fatal injuries and illnesses which could result into temporary or permanent impairment with non-lasting or lasting functional limitations. When this happens, construction enterprises experience productivity losses due to disruption in production process, reduced or low efficiencies, reduced morale and stoppage or suspension orders [7]. Construction enterprises also experience direct and indirect costs of accidents culminating through medical bills, lost wages, increased insurance premiums, compensational costs and administrative costs, among others [8-10]. Regardless, OSC addresses OHS challenges through reducing exposure of construction workers to hazards through minimization of onsite construction activities and onsite workers; eliminating manual handling of hazardous work; ensuring better-organized, uncluttered and safer construction jobsites; eliminating exposure to incremental weather conditions and working from heights, thereby reducing falling accidents; and reducing vulnerability of workers to less apparent but long-term severe health risks which may be responsible for cancer, dermatitis and mesothelioma[11-14].

As OSC continue to gain momentum in the construction sector, new terminologies and concepts for enhancing OSC are constantly appearing in the literature. The information gathered from various publications on OSC indicates a significant number of issues bordering on divergent terminologies, definitions and objectives. For instance, there is lack of consensus with regards to brand name for offsite which has culminated into confusion over its definition and objectives. Lack of consensus on what constitute OSC has led to lack of benchmark for appraising various OSC methods [15]. This trajectory is likely to continue considering the increase in offsite research due to global concerns over social-economic sustainability of the construction industry. Further, ambiguous description of OSC is likely to obtuse and inhibit its financial, environmental and social benefits. The study therefore synthesizes existing knowledge on OSC through scoping review of OSC publications to give a concise description of OSC and its benefits for improving OHS. The paper is structured as follows: Section 2 presents a review methodology for the scoping study. Section 3 and 4 present the descriptive and critical analyses of the review, respectively. Conclusions and future research issues are given in Section 5.

2. Research methodology

A scoping review of literature published between 2000 and 2020 was adopted to gather relevant publications on OSC. The period 2000 to 2020 was chosen to cover the last two decades within which a plethora of OSC research has been published. Popular academic databases, namely, Emerald, Taylor & Francis, ScienceDirect and ResearchGate were used to search for quality research papers on OSC. Since OSC is known by various nomenclatures, the first iteration involved searching of keyword phrases which included *“offsite construction” OR “off-site construction”, “offsite manufacturing” OR “off-site manufacturing”, “offsite production” OR “off-site production”, and “offsite fabrication” OR “off-site fabrication”.* After going through some 98 research papers with the aforementioned keywords, 18 terminologies synonymous with offsite were discovered. The most common ones included *“modern methods of construction”, “modern integrated construction”, “modular construction”, “industrialised housing construction”, “industrialized building systems (IBS)” and “prefabrication”.* As such, the second iteration involved supplementary searches using these phrases which resulted into 282 publications being retrieved. In the third iteration, the abstract or executive summary and conclusion of each paper were skimmed through and papers focusing on peripheral subjects of OSC such as supply chain, building information modelling (BIM), stakeholder relationships and design issues were excluded from the study. Papers that were explicit on development of OSC and description of its benefits were targeted for further analysis. The remaining articles were then further screened out based on whether they are published in a peer reviewed journal or international conferences, or at least examined through a peer-reviewed process or widely recognised industrial reports and textbooks, and the type and source of such article. Only papers from reputable journals and conferences were considered for further analysis. The final number of research papers reviewed in this study for OSC definition and description of its benefits is 34.

There are many limitations to the search methodology used in the study. One important limitation was non-availability of complete access to some of the research papers to the authors. Authors wish to make clear that all the papers reviewed may not have the keywords and all the papers having keywords may have not been reviewed. Many papers were reviewed from cross-references because they contained the required information.

3. Descriptive analysis of the data

Some of the observations, results and discussion based on the scoping review are presented in this section. The results indicate that majority of the papers are either exploratory or empirical. According to [16] while exploratory papers employ surveys to collect data from one or multiple locations at one point of time (cross-sectional) or over a duration of time (longitudinal), empirical papers analyse data taken from existing databases, reviews and case studies. This indicates that the majority of the papers on the description of OSC employ theory verification through empirical and exploratory methodologies. A number of case studies have also been reported, indicating the researchers' appetite to provide real-time developments in OSC operations. There are a few studies based on literature review and a combination of research methodologies. Taken together, the methodologies employed in the reviewed papers justify the need for scoping studies to provide a rapid review and description of OSC, including its benefits. Further, the results indicate that a lot of importance is given to environmental sustainability performance, i.e., waste reduction, energy consumption and carbon emission. Many of the papers also discuss benefits of OSC, mainly to cost, quality and time. Very few papers directly discuss the benefits of OSC to OHS. OHS being one of the project performance parameters, a new OSC focus explicit on OHS benefits and challenges is suggested for future research.

4. Critical analysis of the data

4.1 An overview of offsite terminologies and definitions

This section presents a compilation of the various reported nomenclatures of offsite and their associated definitions. Within the sustainable construction worldview, [17] describes offsite as production and assembly of building components in a climate-controlled environment which are later transported and installed to form a complete building. Offsite is clearly espoused in existing literature under various incarnations and typologies as offsite manufacturing (OSM) in Australia, offsite construction techniques or pre-work/modularization in the United States of America, industrialized building systems (IBS) in Malaysia, modular construction in Canada and Korea, systems building (SB) in Mauritius, modern methods of construction (MMC) in the United Kingdom and industrialized housing construction in Switzerland, Sweden and Finland [4,17,18]. Other terminologies for offsite extant in literature include offsite construction (OSC), modular integrated construction (MiC), offsite prefabrication (OSF) or offsite production (OSP), industrialized house building (IHB) or industrialised housing or construction or system as well as prefabrication, preassembly, premanufacture and offsite industrialization (IO) [4,17,19]. There are minor variations and context in use among these terminologies. However, the various offsite terminologies are used interchangeably in literature and take a common underlying idea in production methods. This is corroborated by [15] who states that various OSC appellations have a common standpoint, i.e., offsite manufacturing of building components. [19] also conclude that all offsite incarnations and typologies are techniques of OSC approach and the terms could be used interchangeably.

However, various and sometimes similar offsite terms have been defined differently by different authors and there appear to be lack of consensus on what constitute offsite. Whilst some authors claim that the terminologies are synonymous [17,21], others proclaim that offsite terminologies like MMC constitute broader offsite technologies which using other offsite terminologies may not describe it satisfactorily [15,21]. To delineate the ambiguity in offsite definitions and provide an acceptable description of offsite, various terminologies and definitions of offsite were reviewed (See Table 1). Arguable, the findings indicate that in the building construction parlance, the various offsite nomenclatures share many similarities, the main single aspect being fabrication of a module in location Y for subsequent installation in location Z. This study therefore suggests that all offsite related terminologies could be used interchangeably in the building construction parlance under one offsite construction umbrella. As such, the study adopts OSC as a collective term to describe all innovative construction techniques (ICTs), innovative building technologies (IBTs) or modern/modular construction techniques (MCTs), which collectively constitute disruptive offsite methods of construction. OSC used in this study is therefore described as manufacturing of building components or modules in a specialised offsite or onsite factory or climate controlled manufacturing environment, using advanced waste elimination and value-adding technologies such as lean methodologies, design for manufacture and assembly, mass production, customization, standardization and modularization, which are in turn either wholly or partially assembled offsite or onsite and transported, assembled and installed to form a complete building structure onsite, in the process that harnesses continuous improvement in the delivery of construction end-products.

4.2 Review and analysis of OSC benefits

A majority of the reviewed papers provide comparison between OSC and traditional construction regarding the environmental sustainability indicators of air pollution, energy and resource consumption, and waste generation. Using greenhouse gas (GHG) as an indicator, a burgeoning literature has reported reduction in GHG emissions in OSC operations from cradle-to-gate [22-27]. Using a case study of prefabricated temporary housing in China, [26] showed reduction in material embodied emissions of 18%, assembly emissions of 17.5% and operational emissions of 91.5%. While [25] found that prefabricated rebar cage (PRC) reduced carbon dioxide emissions by 44.7% during construction, [27] indicated that OSC reduced GHG emissions by 8.4%. Other air protection benefits of OSC include reduced onsite dust, smog formulation, acidification, ozone depletion and ionizing radiation [27,28].

Similarly, OSC literature is awash with conclusions highlighting the reduced energy and resource consumption of OSC operations. The energy consumption reduction theory is attributed to several factors including reusability and recyclability of OSC components and waste reduction. [29] found that electricity consumption for OSC operations was reduced by 41% while 52% savings were realised in diesel usage per unit area. According to [30], recycling could achieve up to 24% energy reduction while waste reduction and high-quality control can save up to 14% of life cycle energy consumption. [31] recorded an overall energy reduction of 8% for OSC operations on public projects. A few more studies indicate OSC benefits to resource consumption and eutrophication, where water, land and fossil resources are preserved. Specifically, [28] and [31] found 41% and 12% reduction in water usage in OSC operations due to dry construction, minimized wet trades and recycling activities, respectively.

Table 1. Terminologies and definitions of offsite.

Term	Definition	Source
OSC	"…the pre-fabrication, manufacture, modularisation, standardisation and preassembly of components. Offsite construction also produces elements or	[38 p7]

	modules and involves substantial factory manufacturing intervention in a controlled environment in which the percentage of onsite added value to the final construction value at project completion is less than 40%."	
	"…involves the production of buildings in an assembly line process, which are trucked to a job site in sections, set in place with cranes, and then assembled to form a complete building."	[19 p2]
OSM	"The creation of a value-adding built environment through a combination of conventional construction procedures and production processes (as in product manufacturing) in which components for construction are produced in a controlled environment, and are transported and installed in the final position onsite"	[15 p227]
	…a process that requires a higher percentage of the value-adding activities being carried out offsite (in a controlled environment) with just installation and finishing done onsite.	[39]
MiC	"A game-changing disruptively-innovative approach to transforming fragmented site-based construction of buildings and facilities into integrated value-driven production and assembly of prefinished modules with the opportunity to realise enhanced quality, productivity, safety and sustainability."	[40 p63]
	"a distinctive OSC technique which embraces the theories of modularity, modularization, design for manufacture and assembly (DfMA), and lean production in providing value-for-money in the construction process."	[4 p2]
MMC	"…a broad range of innovative technologies, techniques and materials which offer opportunities for the continuous improvement of processes in the delivery of construction products through the application of lean theory to remove waste and increase value."	[38 p5]

Reduction in waste generation is another OSC environmental sustainability benefit. Overall, waste reductions of up to 81%, 70%, 12% and 52% were observed by [28,29,31,32], respectively. [33] found that OSC minimizes waste generation through production of building components in controlled factory environment where resource utilization is efficient. In consonance with [34], [28] found that OSC operations enable reusing and recycling of materials through a model of easy assembly and disassembly production of OSC components. Material conservation is singled out in timber formworks, plastering, tiling and concrete work. [28] found waste reduction of 100% and 50% in plastering and, tiling and concrete work, respectively. [35,36] reported waste reduction in timber formwork (up to 87%), concrete work (up to 60%) and plastering (up to 100%). Waste reduction is realised through high quality finish of steel formwork which minimizes hacking of concrete due to dislocation of formwork and excessive plastering to uneven surfaces [36]. Further, the factory setting of OSC operations reduces waste generation through minimization of rework due to improved quality and less defects [28,29].

Notwithstanding that early involvement of project stakeholders minimizes variations during production and construction of OSC components, thereby promoting buildability and reducing waste generation [32], less waste generation is also realised through simplified construction process, reduction in resource and material consumption, better waste management procedures and lower resource input [22,28].

Contrariwise, OHS benefits of OSC have been mentioned in a limited number of papers. However, there are several ways in which OSC is reported to achieve high OHS performance. [15] stated that the OHS potentials of OSC are dependent upon the products, i.e., the type and completeness of the finished components. The products of OSC are divided into four categories, i.e., modular building (MB), non-volumetric preassembly (NVPA), volumetric preassembly (VPA) and components manufacture and subassemblies (CM&SA) [37]. In order to clearly describe the benefits of OSC to OHS, the next section presents the production systems of OSC and their associated OHS potentials, except for CM&SA, which offers the least OHS benefits.

MB is the highest level of OSC production system that entails high degree of offsite manufacturing and assembly of value-added prefinished whole buildings such as office blocks or multi-residence housing [37]. Across the spectrum of offsite systems, the products of MB are the most complete in-factory made components, that are delivered partially or fully finished, with minimal finishing and installation operations performed onsite [15,41]. In fact, MB products are engineered and manufactured to 95% completeness in an offsite workshop [42]. Higher degree of offsite prefabrication and assembly entail significant OHS benefits. According to [12], transferring of hazardous and riskier onsite building operations from site to factory forestalls occurrences of accidents. By its nature, MB entails a higher degree of prefabrication with minimal finishing work performed onsite and the number of onsite workers significantly reduced. The proportion of onsite to offsite workers for OSC operations in MB oscillates between 30% to 70%, respectively [37]. Obviation of the need for a large onsite workforce in the equation of construction process is a huge OHS benefit of MB production system.

Further, MB entails a tectonic shift from manual-intensive construction methods to modern methods. [15] states that production of MB components can be carried out sequentially in a discrete number of independent-stages (linear or semi-automated) or in linear automated sequential stages. As such, MB production system leverages the OHS benefits inherent in a factory environment through proper orientation procedures to facilitate safe working; increased mechanical as opposed to manual handling operations; better control over plant risks; better control of operations and operative’s tasks to schedule job rotation and minimize repetitive tasks and muscular skeletal disorders; overall better cleanliness environment that provides less risk of contamination, falls, trips and slips; work in open spaces as against confined areas; less exposure to dangerous chemicals and substances; improved sequenced trade overlap and interface; 360 degrees access to all parts of the built component; improved overall general welfare facilities; less crowded construction jobsites and reduced ergonomic hazards.

Several onsite MB operations entail significant elimination of OHS risks in the assembly and installation processes. The assembly operations reduce accidents through proper orientation procedures to facilitate safer loading and unloading of components; use of tele-operated vacuum lifters and other mechanical handling equipment; reduction of falling objects as the operations are not reliant on site assembly; reduction of people, onsite operations and installation period thereby minimizing exposure of workers to risks; mechanization of onsite work; reduction of electrocution and associated risks due to less onsite commissioning needs; elimination of the need of working from elevated work platforms and subsequent falling incidents as the work is carried from inside of an edge handrail-protected lift [11,12,43].

Similar to MB production system is volumetric preassembly (VPA) also known as prefabricated and preassembly (PF&PA) or simply, volumetric construction. According to [15], VPA are three-dimensional standard building components such (i.e., plant, bathroom, kitchen and toilet rooms), which enclose usable space, produced offsite and assembled into a complete building onsite. Usually, modular units come fully internally finished with furnishings, equipment and services such as electric and plumbing, and externally with glazing systems, even though in some circumstances, the external finishing work such as brickwork is done onsite. The production process involved in VPA reflects the concepts in MB as regards the product type, the production process and the workforce required in the manufacture and assembly of modules. Basically, the offsite manufacturing of modular units entail element production, module assembly and module completion [37]. As such, VPA has similar OHS benefits inherent in MB with minimal variations in the number of onsite workers needed for module assembly and onsite finishing work. [11] demonstrates the OHS benefits of VPA on a case study of VPA services offered by Corus Living Solutions. Offsite production of modules obviated the need for onsite tradesmen and installation took 3 days out of initial 20 weeks.

Contrastingly, non-volumetric preassembly (NVPA) also referred to as prefabricated and preassembly (PF&SA), entails high degree of offsite prefabrication of building components and high degree of assembly being done onsite [37]. NVPA are also described as two-dimensional building components that do not enclose usable space and include joists and stairways, wall and floor panels, structural frames such as beams, columns, slabs, and pipework assemblies [15,37,41]. The factory production process of NVPA components therefore entail significant OHS benefits as those ascribed for MB and VPA. However, the onsite assembly of the components entail significant number of onsite operations and man hours. Unlike MB and VPA methods, this leads to exposure of construction workforce to accidents intrinsic in traditional construction methods. Regardless, compared to onsite construction methods, NVPA improves OHS performance of construction enterprises to a large extent. Through an analysis of safety method work statement for installation of a wall panel, [12] demonstrated the OHS superiority of NVPA over traditional construction methods. The analysis showed that the installation of the prefabricated panel was associated with 34 risks compared to 53 risks for the traditional method, representing 34% increase. Similarly, a case study by Redrow Housing estate on the installation of precast post-tensioned concrete beams indicated significant reduction in number of onsite workforce (i.e., only four trained operatives and a crane driver) as well as significant reduction in installation time (i.e., 85 minutes) [11]. The significant reduction of operatives and working time is advantageous to OHS as a small workforce is easy to manage while reduction in working time reduces the exposure of construction workers to OHS risks.

5. Conclusion and further research

The quest to address poor performance within the construction industry is providing momentum for cumulative research in OSC. The scoping review was aimed at providing a clear definition of OSC and description of its OHS benefits. A number of conclusions could be drawn from the review. First, the findings indicate that there are multiple terminologies associated with the term offsite which could be grouped as follows: ‘pre’ (i.e., prework, preassembly, prefabrication and premanufacture), ‘building’ (i.e., IBS, SB and IHB), ‘offsite’ (i.e., OSC, OSM, OSF, OSP and OI), ‘modular’ (i.e., modular construction, MiC and modularization) and ‘modern’ (i.e., MMC). Although there appear to be minor variations in the definitions of the terms, almost all terms cover concepts that distinguish offsite from traditional construction approach. The common aspects in definitions of various offsite terminologies are the offsite production of building components and the use of advanced value adding technologies. A broader and working definition that encompasses various offsite concepts has been provided. Second, OSC appear to be an evidenced sustainable solution to ill-performances of the construction industry as it addresses all the three ‘bottom lines’ of environmental, social and financial sustainability. Third, a huge number of OSC papers highlight its benefits to energy and resource consumption, waste generation and carbon emissions. A limited number of papers directly address the OHS performance of OSC operations. A new OSC focus that is explicit on OHS benefits and challenges is suggested for future research.

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7. References

[1] Kovács G and Kot S 2017 Economic and social effects of novel supply chain concepts and virtual enterprises J. Int. Stud. 10 (1): 237-254.
[2] Latham M 1994 Constructing the team - final report of the government/industry review of the procurement and contractual arrangements in the UK construction industry (London: HMSO).
[3] Egan J 1998 Rethinking construction-the report of the construction taskforce (London: Construction excellence).
[4] Wuni IY and Shen GQ 2020 Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. J. Cleaner. Prod. 249. 119347. https://doi.org/10.1016/j.jclepro.2019.119347
[5] Abanda FH, Tah JHM and Cheung FKT 2017 BIM in offsite manufacturing for buildings J. Build. Eng. 14 (2017): 89-102.
[6] International labour office 2001 Guidelines on occupational safety and health management systems ILO-OSH 2001 [online]. Geneva: International Labour Organisation. Available from: www.ilo.org/wcmsp5/groups/public/---ed.../---safework/.../wcms_107727.pdf
[7] Fend Y 2015 Factors influencing workplace accident costs of building projects Int. J. Constr. Manag. 3 (11): 79-92.
[8] Gavious A Mizrahi S Shani Y and Minchuk Y 2009 The costs of industrial accidents for the organisation: developing methods and tools for evaluation and cost-benefit analysis of investment in safety J. Loss Prev. Process Ind. 22 (4): 434-438.
[9] Haupt TC and Pillay K 2016 Investigating the true costs of construction accidents. J. Eng. Des. Tech. 2 (2016): 373-419.
[10] Okoye P and Chuks KO 2014 Exploratory study of the cost of health and safety performance of building contractors in South -east Nigeria. *BJES*. **2** (2014), 21-33.
[11] Health and safety executive (HSE) 2009 *Offsite production in the UK construction industry*. London: HSE. [Accessed 2022 Jan 5]. Available from: https://www.buildoffsite.com/content/uploads/2015/04/HSE-off-site_production_june09.pdf
[12] Ahn S Crouch L Kim TW and Rameezdeen R 2020 Comparison of worker safety risks between onsite and offsite construction methods: A site management perspective. *J. Constr. Eng. Manage.* **146** (9): 050200101-11.
[13] Gibb AGF, Gyi DE and Thompson T 1999 The ECI guide to managing health in Construction (London: Thomas Telford Publishing).
[14] Mckay, L., et al., 2010. Health and safety management of offsite construction: how close are we to production manufacturing? *In:* J. Smallhood and T. Haupt, ed. 4th Triennial International Conference - cib W99, Rethinking and Revitalizing Construction Safety, Health, Environment and Quality. Port Elizabeth, South Africa, 432-441.
[15] Ayinla K 2019 Demystifying the concept of offsite manufacturing method: towards a robust definition and classification system. *Constr. Innov.* **20** (2): 223-246.
[16] Portdar PK, Routroy S and Behera A 2017 Agile manufacturing: a systematic review of literature and implications for future research. *BIJ*. **24** (7): 2022-2048.
[17] Goodier C, Alistair Gibb A, Mancini M, Turck C, Gjepali O and Daniels E 2019 Modularisation and offsite in engineering construction: an early decision-support tool. *Proc. Inst. Civ. Eng. Civ. Eng*. **172** (6), 3-14.
[18] Musa MF, Mohammad MF, Mahbub R and Yusof MR 2014. Characteristics of modular construction: meeting the needs of sustainability and innovation. *2014 IEEE Colloquium on Humanities, Science and Engineering (CHUSER 2014).* 2014. Malaysia. 215- 221.
[19] Wuni IY and Shen GQ 2019 Holistic review and conceptual framework for the drivers of offsite construction: a total interpretive structural modelling approach. *Buildings.* **9** (5): 1-24.
[20] Arif M and Egbu C 2010 Making a case for offsite construction in China. *J. Eng. Constr. Arch. Manag*. **17** (6): 536-548.
[21] Goodier GI and Gibb AGF 2007 Future opportunities for offsite in UK. *J. Constr. Manag. Econ.*

25 (6): 585-595.
[22] Monahan J and Powell JC 2011 An embodied carbon and energy analysis of modern methods of construction in housing: a case study using a lifecycle assessment framework. *Energy Build.* **43** (1): 179-188.
[23] Quale J, Eckelman K, Williams K, Sloditskie G and Zimmerman JB 2012 Comparing environmental impacts of building modular and conventional homes in the United States. *J. Ind. Ecol.* **16** (2): 243-253.
[24] Svajlenka J and Kozlovska M 2017. Modern method of construction based on wood in the context of sustainability. *Civ. Eng. Environ. Syst.* **34** (2): 127-143.
[25] Teng Y and Pan W 2019 Systematic embodied carbon assessment and reduction of prefabricated high-rise public residential buildings in Hong Kong. *J. Clean. Prod.* **238.** https://doi.org/10.1016/j.jclepro.2019.117791
[26] Dong L, Wang Y, Li HX, Jiang, B and Al-hussein M 2018 Carbon reduction measures based LCA of prefabricated temporary housing with renewable energy systems, *Sustainability* **10** (3). https://doi.org/10.3390/su10030718
[27] Sandanayake M, Luo W and Zhang G 2019 Direct and indirect impact assessment in off-site construction – A case study in China. *Sustainable Cities and Societies.* 48 (1). https://doi.org/10.1016/j.scs.2019.101520
[28] Jaillon J and Poon CS 2008 Sustainable construction aspects of using prefabrication in dense urban environment: a Hong Kong case study. *Const. Manag. Econ.* **26** (9): 953-966.
[29] Cao X, Li X, Zhu Y and Zhang Z 2015 A comparative study of environmental performance between prefabricated and traditional residential buildings in China. *J. Clean. Prod.* **109** (2015): 131-143.
[30] Hong J., *et al.,* 2016. Life-cycle energy analysis of prefabricated building components: an input–output-based hybrid model. *J. Clean. Prod.* **112** (4): 2198-2207.
[31] Shen K, Cheng C, Li X and Zhang Z 2019 Environmental cost-benefit analysis of prefabricated public housing in Beijing. *Sustainability.* 11 (1). https://doi.org/10.3390/su11010207
[32] Jaillon L, Poon CS and Chiang YH 2009 Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong. *J. Waste Manag.* **29** (1): 309-320.
[33] Correia JM, Sutrisna M and 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.* **6** (18): 1449-1468.
[34] Lachimpadi SK, Pereira JJ, Taha MR and Mokhtar M 2012 Construction waste minimisation comparing conventional and precast construction (mixed system and IBS) methods in high-rise buildings: a Malaysia case study. *Resources, Conservation and Recycling.* **68** (2012): 96-103.
[35] Tam CM, Tam VWY, Chan JKW and Ng WCY 2006 Cutting construction wastes by prefabrication. *Int. J. Constr. Manag.* **6** (1): 15-25.
[36] Tam CM, Tam VWY, Chan JKW and Ng WCY 2005 Use of prefabrication to minimize construction waste – a case study approach. *Int. J. Constr. Manag.* **5** (1): 91-10.
[37] Jonsson H and Rudberg M 2015 Production system classification matrix: matching product standardization and production system design. *J. Constr. Eng. Econ.* **141** (6). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000965
[38] Ofori-Kuragu JK and Osei-Kyei R 2021 Mainstreaming premanufactured offsite processes in construction-are we nearly there? *Const. Innov.* **21** (4): 743-760.
[39] Pan W and Hon CK 2020 Briefing: Modular integrated construction for high-rise buildings. Proceedings of the Institution of Civil Engineers – Municipal Engineer. **173** (2): 64–68.
[40] Gibb A 2001 Standardization and pre-assembly-distinguishing myth from reality using case study research. *J. Constr. Manag. Econ.* **19** (3): 307-315.
[41] Smith RE 2016. Offsite and modular construction explained. Salt Lake City, Utah, United States of America: National Institute of Building Services.

[42] Bikitsha L and Haupt TC 2011 Impact of prefabrication on construction site health and safety: perspective of designers and contractors. ASOCSA – 6th Built Environment conference, 11th January, Sandton, Johannesburg. South Africa.: Research Gate, 196-211.