Lean and agile integration within offsite construction using discrete event simulation

A systematic literature review

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Abstract

Purpose – The purpose of this study is to systematically analyse and synthesise the existing research published on offsite manufacturing/construction. The study aims to highlight and associate the core elements for adopting the offsite concept in different construction contexts. This ultimately facilitates the enhancement of the offsite uptake.

Design/methodology/approach – The research study was carried out through a systematic literature review (SLR). The SLR was conducted to identify and understand the existing themes in the offsite research landscape, evaluate contributions and compile knowledge, thereby identifying potential directions of future research. The grand electronic databases were explored to gather literature on the offsite concept, lean and agile principles and simulation. A total of 62 related articles published between 1992 and 2015 have been included in this study. The relevant literature was systematically analysed and synthesised to present the emerging offsite themes.

Findings – The descriptive and thematic analyses presented in this paper have identified related offsite research studies that have contributed to setting a firm foundation of the offsite concept in different construction contexts. Each of the 62 articles was examined for achieving the aim and objectives of this study, the method of data collection and coverage of offsite themes. The results of the analyses revealed that the articles mostly provide information on the offsite concept and its definitions (53 per cent) and offsite barriers and/or drivers (27 per cent). However, limited attention has been paid to the integration of lean and agile principles (13 per cent) and simulation (7 per cent) within the offsite concept, which are therefore more open to research within the offsite concept.

Research limitations/implications – The literature review highlights the main themes and components of the offsite construction concept. This forms a solid basis and motivation for researchers and practitioners to build on to enhance the uptake of the offsite concept in different contexts. This study also presents a research roadmap within the offsite concept, along with a recommendation for further research to be conducted using the research framework proposed in this study. The framework could lead to validation of using simulation to integrate lean and agile principles within the offsite concept.

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Originality/value – This paper presents a systematic review of the literature related to offsite construction in different contexts. The emerging components, that is, offsite definitions, drivers and/or barriers, lean and agile principles and simulation have been highlighted and discussed thematically. A research framework that enables pursuit of the integration of lean and agile principles offsite through the lens of simulation has been proposed. The framework is expected to open up new opportunities on the effectiveness of offsite development in different contexts.

Keywords Modelling and simulation, Systematic literature review, Future roadmap and framework, Lean and agile principles, Offsite construction, Offsite manufacturing

Paper type Literature review

Introduction

Koskela (1992) was the first scholar to propose construction as a production process, stating that the construction process is a flow of material and information, transformation and creating value. Therefore, new philosophies from manufacturing systems could be transferred and fitted to manage the construction processes. This led to the development of new construction techniques or modern methods of construction (MMC) (Slaughter, 1998). The MMC can be classified according to the type of product produced and the location of production. MMC products include panelised (structural insulated panels), volumetric units (e.g. bathroom and kitchen pods), hybrid and subassemblies and components (e.g. floor or roof cassettes and precast concrete foundation assemblies) (Pan and Goodier, 2012). Based on the location of production, MMC are classified into offsite manufacturing/construction (OSM/OSC) and onsite production (Burwood and Poul, 2005; National Audit Office, 2005). The offsite concept includes the production of house elements in offsite factories before the elements are transported for assembly at the construction site (Russell *et al.*, 2012). This concept offers numerous benefits to stakeholders involved in the construction process, including reduction in construction time, defects, occupational health and safety risks, environmental effects and whole life cost (Pan and Goodier, 2012; Pasquire and Connolly, 2002). Moreover, the offsite technique improves the quality of the fabricated house elements/modules, productivity, performance and profitability of a house builder (Zhai *et al.*, 2014a).

The offsite concept has been operating in the house building sector of many countries, such as Australia, China, the UK, Germany, Sweden, The Netherlands, Japan, and the USA (Blismas and Wakefield, 2009a, 2009b; Goulding *et al.*, 2015; Nadim and Goulding, 2011; Pan and Goodier, 2012; Polat, 2008). The mainstream research studies reviewed focus on discussing the offsite concept and its definitions (i.e. offsite types, processes, materials used and connectors). Nevertheless, the uptake of the offsite concept faced several barriers. These barriers are addressed in several studies in different contexts. For example, Blismas and Wakefield (2009a, 2009b) identified and assessed the offsite barriers to house building in Australia. The main barriers were a longer lead time, freezing the house design at an earlier stage and a skilled labour shortage. Nadim and Goulding (2011) summarised the resistance to adopting OSC in four European countries (Germany, The Netherlands, Sweden and the UK). The resistance was deeply rooted in unsuccessful past experiences associated with the OSM. Zhai *et al.* (2014a) list the main barriers to offsite production in the Chinese residential industry: poor integration in the supply chain, inability to freeze the design early and higher demand for site-specific and associated logistics for pre-finished element protection. Lu and Liska (2008) identify the top three challenges of using OSC techniques in the USA as the inability to make changes on site, transportation constraints and limited design options. Overcoming these challenges requires efficient management of the two working locations of the offsite supply chain concurrently (Vrijhoef and Koskela, 2000).

Some studies recommend applying lean and agile manufacturing principles to manage the offsite supply chain (Blismas, 2007; Goodier and Gibb, 2007; Lu *et al.*, 2011; Manley *et al.*, 2009; Manufactured Housing Research Alliance, 2003). These recommendations should be examined further for any opportunity to enhance the use of lean and agile principles in the offsite supply chain where different management tools are used that are complementary to those used in traditional house building. The principles can be integrated in the supply chain using a decoupling point (DP). The DP refers to the intervention of the end-user/client order in the offsite supply chain. Therefore, there are different *what-if* scenarios to integrate lean and agile principles. These scenarios require structural changes to the traditional construction supply chain. Simulation can be applied to evaluate each what-if scenario. Simulation mimics the behaviour of the real offsite system and predicts the results regarding cost or completion time before implementation. There are inadequate studies on integrating lean and agile principles within the offsite supply chain and on applying such integration using the lens of simulation. In addressing these important knowledge gaps, this research provides a systematic literature review (SLR) of the offsite literature by adopting a robust and structured methodology such as that proposed by Denyer and Tranfield (2009). The SLR has been applied in supply chain management (Alexander *et al.*, 2014) and construction management (Rutten *et al.*, 2009) research. The purpose of this paper is to deliver a systematic review that provides a comprehensive analysis of the OSC/OSM topic in the literature.

This paper contributes to the OSC research by synthesising the main themes and components that affect offsite uptake, developing a research roadmap for an offsite and future research framework to enable further research integrating lean and agile principles and simulation within the offsite supply chain. This paper is structured as follows. The next section demonstrates a comparison between house building and the manufacturing industry. The third section reviews the literature on lean and agile principles in the house building industry. The fourth section presents the aim and objectives of the research. The fifth section describes the SLR methodology, including a detailed description of the search and selection criteria of the relevant literature. The SLR results, including the descriptive and thematic analyses, are demonstrated in the sixth section. The seventh section presents the research results in light of the research objectives. Finally, the paper concludes with the main research findings, offsite research and practice implications, limitations of the study and avenues for further investigation.

A comparison between house building and the manufacturing industry

It is well recognised that the performance of the construction industry can be improved through lessons learned from the manufacturing industry (Gann, 1996; Goulding *et al.*, 2015; Höök and Stehn, 2008; Nadim and Goulding, 2011). It is, therefore, imperative that we understand house building industry features and their similarities with the manufacturing industry. According to Gann (1996), there are significant differences in the nature of the manufacturing and construction processes, as listed in Table I. Manufacturing is a well-automated process which operates in a controlled environment, whereas house building is a labour-intensive process which is commonly performed in the open environment, exposed to weather and other influences. House building comprises several construction steps, whereas in manufacturing, a few assembly steps lead to the finished product. Moreover, the manufactured product and process design are typically undertaken within the same organisation, whereas in house building, different companies typically perform design and/or construction (Marshall *et al.*, 2013).

The house building sector is described as the portion of the construction industry that is similar to the manufacturing industry (Bashford *et al.*, 2003). As a result, the house building process could be viewed as a production system with a flow of information and materials to produce a house. According to Naim and Barlow (2003), there are similarities between house building and producing personal computers (PCs). A PC and a house could be broken down into simple components. In addition, all PCs and houses are practically the same. Although there is little to distinguish the products, it is still necessary to customise the product to meet customer demands. Gann (1996) found similar benefits from a comparison between industrialised residential construction (offsite) and automobile manufacturing in Japan. Therefore, lean and agile manufacturing principles have been successfully used to produce attractive, customised and affordable houses. The Partnership for Advanced Technology in Housing, administrated by the US Department of Housing and Urban Development, suggests the adoption of manufacturing principles by the manufactured houses (offsite)

Table I.
Main difference between house building and manufacturing industries

Distinguishing attributes	House building	Manufacturing
Kind of production	Project type One-of-a-kind project nature Labour-intensive Changing work places One delivery	Continuous production Mass production/off-line production High level of automation/ less labour-intensive Fixed work places Continuous deliveries
Resources	Variable resources	Fixed resources
Nature of management	Project management techniques; CPM and PERT	Manufacturing systems; JIT, lean and agile
Production planning	Push system	Push and pull system
Work environment	Controlled work environment	Weather controls the work environment
Key participants	House buyer, supplier, designer, contractor and employee	Markets, supplier, designer, manufacturer and customer
Lean thinking approach	Lean construction	Lean enterprise
Agile concept	BIM	Agile enterprise
Supply chain management	Fragmented supply chain	Continuous supply chain
Product life span	Long product life span	Short product life span
Customer involvement	House customer is involved in design stage	End-user is not involved in the production, widely consulted in the marketing

(Manufactured Housing Research Alliance, 2003; Partnership for Advancing Technology in Housing, 2002).

Lean and agile and simulation concepts in offsite construction

The lean concept was developed in the Toyota Production System. It is an integrated socio-technical system that comprises management practices that can be applied to eliminate waste (Purvis *et al.*, 2014). The lean application into the construction environment was first introduced by Koskela (1992). The transformation-flow-value (TFV) concept of production was developed as a new perspective to improve construction performance (Mossman, 2009). According to the TFV concept, construction production consists of three corresponding processes: a transformation of materials into standing structures, a flow of the materials and information through various production processes and value creation for customers through the elimination of value loss. The agile concept, on the other hand, became popular in 1991. Sharifi and Zhang (1999) state that a new competitive environment was the key driver for changes in manufacturing. The competition criteria are continuous improvement, rapid response and quality improvement. The initiative of using the agile concept in the construction industry was established as a direct response to the Latham report (Latham, 1994). The report highlighted the UK construction industry requirement to reduce construction costs by 30 per cent by the year 2000. To achieve this target, the whole industry needed to change. Benchmarking was the method used to stimulate the required change in construction practices (Lee, 2003). Naim *et al.* (1999) suggested the employment of agile principles in construction supply chains to achieve profitable opportunities in dynamic markets. Agile construction exemplifies the characteristics of visibility, responsiveness, productivity and profitability (Daneshgari, 2010).

The integration of lean and agile principles answers all the production issues in world-class market competition (Towill and Christopher, 2002). Combining lean and agile principles within the whole supply chain is known as *leagile* (Naylor *et al.*, 1999). Table II shows the characteristics of lean, agile and leagile supply chains accumulated from Agarwal *et al.* (2007). It shows that lean, agile and leagile characteristics relate to the end-user value metrics lead time, service level, cost and quality. Moreover, it presents the connection between the end-user value metrics, the market qualifiers and market winners with the three supply chains. Market qualifiers mean the starting point for every business entering the competitive arena. Market winners refer to the specific capacities needed to win the market Mason-Jones *et al.* (2000a, 2000b). As seen in Table II, the agile concept is suitable for certain conditions, such as volatile and unpredictable demands, high variety of products and innovative products. Some other conditions can also be fulfilled by using the lean concept, including functional products, lead time compression and reducing product cost. An organisation supply chain should include both lean and agile concepts, as the limitation of one will be handled by the strength of the other (Agarwal *et al.*, 2006).

The DP mechanism is used to integrate lean and agile principles within the entire supply chain. The DP separates the supply chain into lean in the upstream and agile in the downstream (Purvis *et al.*, 2014). For competition in dynamic markets, Christopher and Towill (2001) state that supply chains must be in touch with market demand changes, which can be divided into three critical dimensions, namely, variety, variability and volume. The lean concept is an appropriate alternative in high-volume,

Distinguishing characteristics	Lean concept	Agile concept	Leagile strategy
Market demand	Predictable	Volatile	Volatile and unpredictable
Product variety	Low	High	Medium
Product life cycle	Long	Short	Short
Customer drivers	Cost	Lead-time and availability	Service level
Information enrichment	Highly desirable	Obligatory	Essential
Forecast mechanism	Algorithmic	Consultative	Both/either
Typical products	Functional products	Innovative products	Product as per customer demand
Lead time compression	Essential	Essential	Desirable
Waste elimination	Essential	Desirable	Arbitrary
Rapid reconfiguration	Desirable	Essential	Essential
Responsiveness	Arbitrary	Essential	Desirable
Quality	Market qualifier	Market qualifier	Market qualifier
Cost	Market winner	Market qualifier	Market winner
Lead time	Market qualifier	Market qualifier	Market qualifier
Service level	Market qualifier	Market winner	Market winner

Table II. Characteristics of lean, agile, and leagile supply chains

low-variety and low-predictable change environments. The agile concept is the best option in high-variety, low-volume and high-predictable change environments. The real demand visibility is limited in most supply chains. The supply chains may be lean before DP and agile beyond DP. There are two DPs in the leagile supply chains; material DP that should ideally be located as far downstream as possible to be close to the final marketplace and information DP that should be located as far upstream as possible in the supply chain (Mason-Jones *et al.*, 2000a, 2000b). Agility beyond the DP is explained by the principle of postponement using a generic or modular inventory to postpone the final commitment, whereas the final assembly or customisation depends on real demand (Sackett *et al.*, 1997).

The leagile supply chain has the capability of adding value to the house customer through different strategies by the position of the DP, as shown in Figure 1. The leagile supply chain mainly focuses on waste removal and responsive mechanisms through applying lean and agile practices, tools and techniques.

Lean and agile principles broadly aim to provide more control over value specification and demand while designing the process to eliminate waste and optimise efficiency by empowering workers and seeking continuous improvement (Blismas and Wakefield, 2009a, 2009b). The principles are suitable for addressing the fragmented nature of the offsite supply chain by managing both the building site and the offsite factory (Azambuja and O'Brien, 2009; Ballard and Howell, 2004; Vidalakis *et al.*, 2013; Vrijhoef and Koskela, 2000). Lean principles could manage the offsite processes of producing building components and modules. On the other hand, agile principles would be suitable for responding proactively to any uncertainties/variations at the construction site, such as changes in customer demand or site conditions. Therefore, some studies have recommended applying lean and agile principles to efficient offsite supply chain operations (Blismas, 2007; Goodier and Gibb, 2007; Lu *et al.*, 2011; Manley *et al.*, 2009; Manufactured Housing Research Alliance, 2003).

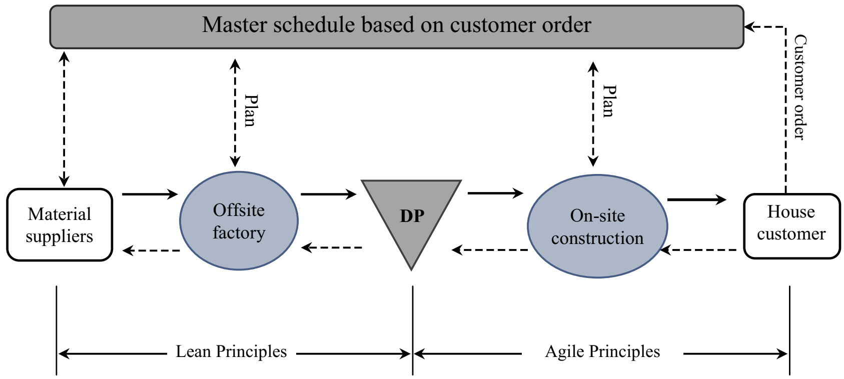

Figure 1.
Lean and agile concepts within offsite supply chain

Despite these recommendations, developing a well-established, integrated and concerted lean and agile research with the offsite concept is still limited. In essence, these recommendations should be examined further by initially reviewing the research works conducted on using these principles within the offsite landscape in several contexts. After having looked at some offsite-related articles (i.e. Johnsson, 2013; Mostafa *et al.*, 2014a; Naim and Barlow, 2003; Sackett *et al.*, 1997), it is evident that the DP is deemed an essential mechanism to integrate the two principles within the whole offsite supply chain. The DP refers to the intervention of the client order in the offsite supply chain. Therefore, there are different what-if scenarios to integrate lean and agile principles, which require re-engineering and structural changes in the offsite supply chain. Simulation can be applied to predict the results of these scenarios regarding cost or completion time before implementation. However, there are inadequate studies linking lean and agile principals within the offsite supply chain using the lens of simulation.

Aim and objectives

The aim of this paper is to develop a research framework for future studies on lean and agile integration within the offsite landscape using the lens of simulation. This research followed the defined aim by locating the gaps in the offsite knowledge area that are essential for enhancing the adoption of OSC. The authors formulated the research questions using the neglect gap-spotting mode defined by Sandberg and Alvesson (2011). The research identified the overlooked and under-researched areas in the existing literature. This paper examines the ongoing development in the offsite landscape in different contexts to establish a comprehensive understanding of standardised characteristics and requirements. To achieve the aforementioned aim, four objectives were drawn up for the research:

(1) providing a clear understanding of lean and agile principles and their development from the manufacturing industry to the house building industry;

(2) highlighting the main themes that influence OSC uptake in the existing literature;

(3) exploring the state-of-the-art knowledge on lean and agile principles within the offsite concept; and

(4) developing a future research framework that facilitates the integration of lean and agile principles using simulation within the offsite supply chain.

Research methodology

This paper used an SLR to identify and expand the existing body of knowledge on the offsite concept. Okoli and Schabram (2010) indicate that an SLR is a comprehensive and reproducible method for identifying, evaluating and synthesising the existing body of completed and recorded work produced by researchers, scholars and practitioners. The SLR has become an essential scientific activity (Denyer and Tranfield, 2009), because of its power to combine evidence in existing studies and its ability to create new knowledge, which is essential for conducting new research. SLR has been applied in the management research to close the research-practice gap (Rousseau *et al.*, 2008). Some research in different contexts state the necessity for conducting more research on applying lean and agile concepts in the offsite supply chain (Blismas, 2007; Lu *et al.*, 2011; Manufactured Housing Research Alliance, 2003; Mostafa *et al.*, 2014a). These researchers believe that the success of lean and agile concepts in the manufacturing industry can be transferred to the construction industry. They recommend that the concepts need to be adjusted to fit the offsite supply chain. Therefore, this paper conducted an SLR of the research articles about offsite construction published in renowned academic databases from 1992 to 2015. These dates were chosen to ensure that significant information relating to the results of this research was included.

Research approach and stages

The research approach in this study included a ten-step SLR, divided into three stages, as demonstrated in Figure 2. The steps and stages used in this research were modified from several academic sources, such as Denyer and Tranfield (2009), Okoli and Schabram (2010) and Thomas *et al.* (2004) to accomplish the research aim and objectives.

Stage 1: planning the review and searching the literature

The first stage involved review planning and searching the literature. The plan for an SLR consists of identifying the literature review purpose and protocol (Denyer and Tranfield, 2009; Tranfield *et al.*, 2003). The purpose of this study was clearly defined and demonstrated in the section on aim and objectives. The literature review protocol was outlined and organised to conduct the SLR steps to achieve the purpose of this study. Searching for literature begins after completing the literature review plan. The search for related publications was carried out through an examination of various scholarly sources, including books, journal articles, conference proceedings and reports. The most efficient way for searching the literature is using electronic resources (Levy and Ellis, 2006). The following electronic databases were searched: Emerald, Elsevier, Taylor and Francis, American Society of Civil Engineers and International Council for Research and Innovation in Building and Construction (CIB) world building congress.

Searching the abovementioned databases was conducted using key terms to avoid unbiased research and to expel unnecessary material (Duff, 1996). The authors used the following research keywords: “offsite manufacture”, “offsite manufacturing”, “off-site manufacturing”, “offsite production”, “offsite construction”, “prefabrication/prefabricated”, “lean”, “agile” and “simulation”. As articles were reviewed, other cited articles were added (the principle of snowballing) (Choong *et al.*, 2014). The keywords identified in those new articles were then used to create additional search strings with

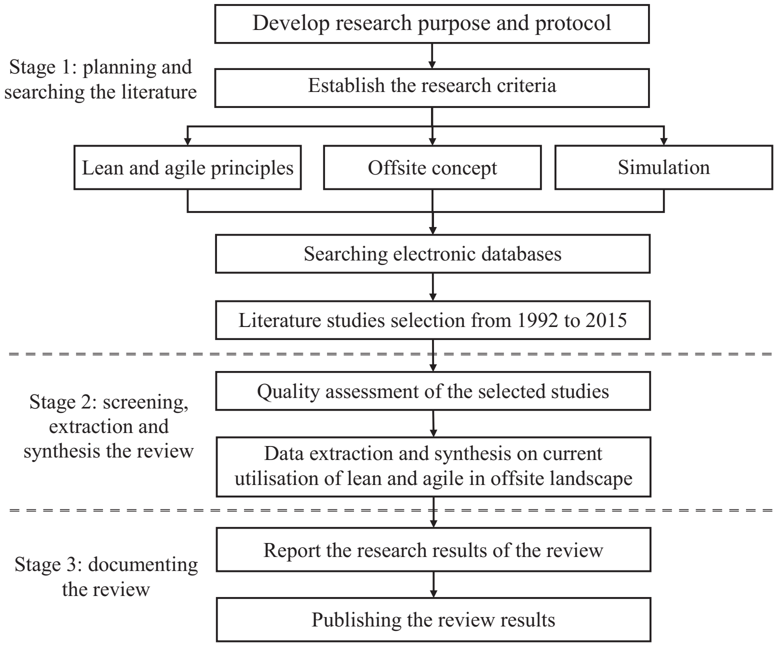

Figure 2.
Research stages and processes framework

Boolean connectors (AND, OR and NOT). Searching for related papers was limited to papers published between 1992 and 2015 to make sure that all information was up to date. The authors determined to start from 1992, because that was when Koskela introduced the lean construction concept.

Stage 2: screening

This study determined research inclusion and exclusion criteria to ensure fidelity and comprehensiveness. These criteria are critical to the quality assessment of papers (Booth *et al.*, 2012). In the SLR, the criteria were addressed to clarify the selection of research-related articles. Simplifying research using some criteria (e.g. reviewing the title and then the abstract when needed) saves the researcher time and effort. In this paper, the authors examined research articles by title, abstract and keywords. By these means, all articles that met the inclusion criteria were selected. Only well-known academic databases were searched for academic journals and papers that contained a robust and profound analysis of findings. Some of the collected articles were excluded, as they were out of scope (e.g. maintenance performance evaluation, environmental performance and greenhouse emissions).

Searching the online databases resulted in identification of 935 articles addressing the keywords, as demonstrated in Figure 3. The next screening step involved removing all duplicates according to the title and author. Furthermore, the articles that had not been peer-reviewed were deleted. This process discovered that 251 articles were aligned with the enclosure aspects. Then, the authors read the abstracts and reviewed the full papers, focusing on lean and agile and simulation

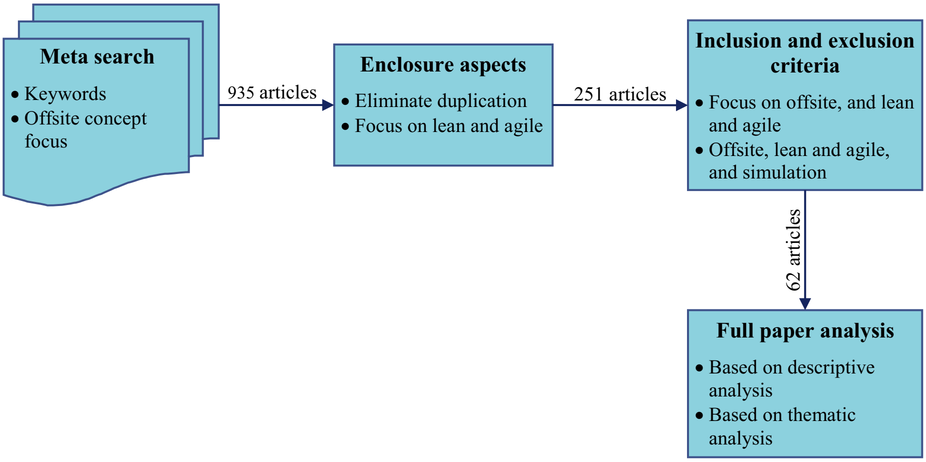

Figure 3. Screening methodology used in this study

practice in the offsite supply chain. Only 62 articles (listed in Table III) met the inclusion and exclusion criteria of this study.

Stage 3: extraction, synthesis and documenting the review

The authors categorised and synthesised the 62 articles using two separate analyses: descriptive and thematic. The descriptive analysis explains the research context, scope and methodologies. Thematic analysis highlights the synthesis of the main results from the extracted literature and provides an outline of future research and practice, as well as gaps in the offsite landscape.

Systematic literature review results

Descriptive analysis

The descriptive analysis identifies the distribution of the 62 publications from 1992 to 2015. The number of articles focusing on offsite techniques has increased significantly since 2008, and specifically in the past three years, across contexts. A summary of statistics, including the research context, method and scope, is provided in Table IV, which uses the same categorisation as Altay and Green (2006).

Around a quarter (25.4 per cent) of the papers on OSC have been published in the Australian context, and 23.7 per cent come from the UK-based context. The percentage of papers targeting the Swedish and global construction contexts (i.e. European countries, developing countries or general) were 13.6 and 11.9 per cent, respectively. The remaining articles were published in the USA, China, Canada, Japan, New Zealand, Iran, Malaysia, Nigeria and The Philippines. The nine research methods used in the selected 62 articles were recorded (Table IV). The majority of studies used case study methodology (with C = 23, 38 per cent) and literature review (with C = 18, 30 per cent) to investigate the offsite topic. The novelty of the offsite concept calls for descriptive and exploratory research approaches. Therefore, it is logical that the mainstream articles applied case studies and literature reviews as the research method (i.e. Arashpour *et al.*, 2015; Bildsten *et al.*, 2011; Kolo *et al.*, 2014a, 2014b; Mostafa *et al.*, 2014a; Shahzad *et al.*, 2015).

Table III. Context, research method, scope and research themes reported by the articles in the systematic review

Serial no.	Author(s) and year	Context	Research method	Scope (areas covered)	Research theme
(1)	Gann (1996)	Japan	Literature review	History of industrialised housing production Toyota production system Japanese industrialized housing production Panel and modular prefab systems Similarities and differences between industrialized housing and car production in Japan	Industrialised house building
(2)	Childerhouse *et al.* (2000)	UK	Literature review	House building value stream House building supply chain strategies Lean, agile and leagility concepts	Lean and agile concepts
(3)	Wing and Atkin (2002)	European countries	Conceptual approach	FutureHome project documentation House building and Europe's economy The FutureHome concept (affordable, decent, modern in its facilities and capable of adapting to changing needs) FutureHome's achievements in Europe Examples of FutureHome innovations	FutureHome modernizations in building systems, automation and IT
(4)	Partnership for Advancing Technology in Housing (2002)	US	Case study	Acceptance of innovative home building technologies Apply manufacturing process and robotic automation to home building Constructability of houses	Home building process into the factory
(5)	Pasquire and Connolly (2002)	UK	Case study	Lean production and construction Advantages of preassembly (onsite, programme, and manufacturing) Lean production for preassembly of HVAC modules Success factors for implementing preassembly Integration of lean enterprise and lean construction	Preassembly of building components Lean construction
(6)	Naim and Barlow (2003)	UK	Case study	Lean and agile in house building supply chain management	Lean and agile concepts in house building industry
(7)	Manufactured Housing Research Alliance (2003)	US	Literature review	Roadmap for manufactured home including five areas: the house, factory, site, market, and the customer Computer-based simulation to predict how homes will perform under normal and extreme loading conditions	Manufactured home processes
(8)	Hampson and Brandon (2004)	Australia	Questionnaire	Environmentally sustainable construction Information and communication technologies for construction OSM	2020 visions for Australia's construction industry
(9)	Lessing *et al.* (2005)	Sweden	Case study	Industrialised housing/OSM of building parts SCM integration for construction process	Industrialised house building/offsite manufacturing
(10)	Blismas *et al.* (2005)	UK	Questionnaire survey	OSP constraints and drivers OSP constraints mitigation	OSP
(11)	Barlow and Ozaki (2005)	Japan	Literature review	Influences on housebuilding in Japan Mass customised housebuilding in Japan Development of mass customised housing suppliers	Building mass customised housing

(*continued*)

Table III.

Serial no.	Author(s) and year	Context	Research method	Scope (areas covered)	Research theme
(12)	Lessing (2006)	Sweden	Case study	Definition of industrialised house building OSM of building parts Production concepts (lean and agile)	Industrialisation characteristics
(13)	Lapointe *et al.* (2006)	Canada	Interview survey	Technologies in the factory built house industry Activities for designing prefabricated Structural systems	Mass customisation in factory-built timber frame home
(14)	Court *et al.* (2006)	UK	Case study	Lean and agile manufacturing Modular assembly Design of a lean and agile construction system for a large and complex mechanical and electrical project	Innovative construction technologies Modular assemblies
(15)	Pan *et al.* (2007)	UK	Interview and questionnaire survey	Perceptions on using offsite MMC Trend of offsite MMC take-up Barriers and drivers of using offsite MMC Recommended strategies for offsite uptake	Construction industry views on using offsite technologies Barriers and drivers of offsite
(16)	Blismas (2007)	Australia	Case study-CRC Research Report	Manufacturing principles (e.g. lean and agile) Current state/future directions of offsite manufacture in Australia OSM barriers and drivers in Australia	OSM
(17)	Höök and Stehn (2008)	Sweden	Case study	Lean principles in construction Factory production of industrialised housing Applicability of lean principles and practices into the industrialised housing	Lean principles and practices Industrialised housing
(18)	Lu and Liska (2008)	US	Case study	The use of offsite construction techniques Perceived Outlook of Using Offsite Construction Techniques Designers and general contractors perception of offsite construction in US	Reasons and challenges of using offsite construction techniques
(19)	Neelamkavil (2009)	Canada	Literature review	Elements of automation in prefab industry (e.g. automated design, procurements, and construction job site) Virtual Reality and Simulation in Prefab Planning for Prefab Automated Assembly	Automation in prefab industry
(20)	Davis (2009)	UK	Conceptual approach	Using SSM Lean supply in construction	SSM to develop lean supply in construction
(21)	Manley *et al.* (2009)	Australia	Content analysis-CRC research report	Defining the current innovations in the Australian built environment Sustainable innovation approaches Offsite manufacture	Innovative practices for Australian built industry
(22)	Johnsson and Meiling (2009)	Sweden	Case study	Timber module prefabrication (design, manufacture and construction processes) Defects in OSC (types, measures to correct, occurrence)	Defects in OSC process
(23)	Court *et al.* (2009)	UK	Case study project	Development of an innovative method for assembling, transporting, and installing mechanical and electrical modules, Achieving modularization with or without offsite manufacturing capability	Modular assembly

(*continued*)

Serial no.	Author(s) and year	Context	Research method	Scope (areas covered)	Research theme
(24)	Blismas and Wakefield (2009a, 2009b)	Australia	Literature review	Sustainable construction Sustainable aspects through offsite manufacture OSM definition OSM drivers and barriers	OSM drivers benefits for sustainability in construction
(25)	Zimina and Pasquire (2010)	UK	Literature review	Offsite and lean construction definitions Modularisation for leaner offsite strategy Offsite process for construction	Offsite strategy using lean thinking
(26)	Eriksson (2010)	Sweden	Case study	Lean construction elements/stages Implementation of lean aspects	Lean construction
(27)	Nadim and Goulding (2010)	UK	Questionnaire survey	UK construction industry perception on OSP OSP skills requirements Factors inhibiting the wider use of OSP	OSP
(28)	Amir Zavichi *et al.* (2010)	Iran	Case study	Lean construction philosophy Mistake proofing adopting in construction industry Methods to achieve mistake proofing (e.g. use modularisation)	Mistake proofing implementation in construction projects Lean construction
(29)	Nadim and Goulding (2011)	European countries	Questionnaire survey	OSP and the concept of industrialisation OSP patterns (product, people, technology, business process and market)	OSP
(30)	Kenley *et al.* (2011)	Australia	Literature review	Communication issues between offsite and on-site Construction sustainability using life-cycle analysis	LCA for on-site and offsite processes
(31)	Lu *et al.* (2011)	Sweden	Case study	Home building approaches such as EFC and SDP Leanness and agility using VSM DES	Lean, agile and DES
(32)	Doran and Giannakis (2011)	UK	Case study	Modular practices/principles in construction sector supply chain Limitations and potentials of modular construction Relationship/Supplier integration matrix	Modular construction
(33)	Bildsten *et al.* (2011)	Sweden	Case study	Market and value driven purchasing Kitchen cabinets production Industrialised housing	Value driven of kitchen cabinets and industrials housing
(34)	Azman *et al.* (2011)	Malaysia	Literature review	Prefabrication in the construction industry Drivers and challenges of adopting modern methods of construction The IBS status and trends of Malaysian construction industry	IBS
(35)	Al-Bazi and Dawood (2012)	UK	Case study	Crew allocation in precast industry Architecture of crew allocation system Simulation and genetic algorithm	DES
(36)	Lu *et al.* (2012)	Sweden	Literature review	Stakeholders value for industrialized building Lean-agile supply chain for Swedish industrialized housing Discrete event simulation in construction BIM-based lean-agile supply chain	IBS/lean and agile DES

(*continued*)

Table III.

Table III.

Serial no.	Author(s) and year	Context	Research method	Scope (areas covered)	Research theme
(37)	Kenley *et al.* (2012)	Australia	Literature review and conceptual model	OSM adoption issues OSM procurement, information flow, and resources IT-based decision making tool to facilitate the OSM adoption	IT decision model for OSM adoption
(38)	Zhai *et al.* (2013)	China	Questionnaire survey	The significance relationship between offsite production and sustainable construction Impediments of offsite production uptake Increasing the level of sustainability via offsite production	Driving forces and potential barriers for OSP uptake
(39)	Goulding *et al.* (2013)	UK	Mixed-method	Modern methods of construction and offsite manufacturing SMART components and connectors OSM themes (process, design, technology, manufacturing, construction)	OSM supply chain relationships, opportunities and challenges
(40)	Wynn *et al.* (2013)	Australia	Design Science methodology	Business process management Offsite manufacture Construction process workflow The YAWL language	Construction processes Construction workflow using YAWL
(41)	Rohani *et al.* (2013)	General	Literature review	Modern methods of construction (OSM and non-OSM) Visualisation in construction management	OSM Simulation
(42)	Dalton *et al.* (2013)	Australia	Interview and focused group	Innovation in suburban house building Barriers of innovation Practice in construction scheduling House production modelling	House building scheduling HCSM
(43)	Arif and Pannell (2013)	UK	Focused group	Housing situation in the UK OSC	Challenges of OSC
(44)	Shahzad and Mbachu (2013)	NZ	Interview and questionnaire	Benefits of prefabrication Prefabrication constraints	Identify and prioritise the constraints of prefabrication
(45)	Boyd *et al.* (2013)	Australia	Case study	OSC forms Offsite preassembly, hybrid, panelised, and modular systems Barriers and drivers for OSC	OSC
(46)	Johnsson (2013)	Sweden	Case study	Production strategies in industrialised house building Engineer-to-order strategy	Industrialised building and supply chain structures
(47)	Mostafa *et al.* (2014a)	Australia	Literature review	Enhancing OSM adoption in Australia Introduced a lean and agile concepts to OSM	Lean and agile concepts for OSM supply chain
(48)	Mostafa *et al.* (2014b)	Australia	Literature review	Australian housing affordability OSM supply chain Leagile strategies using decoupling point	OSM Lean and agile principles
(49)	Mostafa *et al.* (2014c)	Developing countries	Literature review	Current situation and opportunities OSM in developing countries Two leagile strategies for OSM in developing countries	Lean and agile concepts for OSM supply chain
(50)	Li *et al.* (2014)	General (developed countries)	Literature review	Managing the prefabricated construction Research interests themes on prefab (e.g. design, production strategies)	Research topics on prefab industry

(*continued*)

Serial no.	Author(s) and year	Context	Research method	Scope (areas covered)	Research theme
(51)	Khalfan and Maqsood (2014)	Australia and China	Literature review	Current state of OSM in the last five to seven years within Australian and Chinese residential sectors	Offsite manufacturing
(52)	Goulding *et al.* (2015)	Not mentioned	Focused group	Main core issues of OSP (construction, manufacturing and design) Drivers of each issues underlying people, process and technology categories OSP research roadmap	OSP cores issues and its drivers with people, process and technology
(53)	Kolo *et al.* (2014)	Nigeria	Literature review	Housing issues in Nigeria Opportunities of adopting OSM in Nigeria Benefits of OSM	Benefits of OSM for Nigeria house building supply
(54)	Ganiron and Almarwae (2014)	The Philippines	Interview	History of modular houses and classification Modular manufacturing process Structural characteristics of prefabricated components	Prefabricated Technology in a Modular House
(55)	Duc *et al.* (2014)	Australia	Literature review	OSM of housing in other contexts such as Scandinavian, Germany, US, UK and Japan. OSM drivers and barriers in Australia	OSM
(56)	Alazzaz and Whyte (2014)	Australia	Literature review	OSC background Adoption and value of OSC Benefits of OSC	Benefits of OSC
(57)	Jonsson and Rudberg (2013)	Sweden	Case Study	Production strategies in construction Classification of production systems in construction	Drivers and barriers of industrialisation
(58)	Zhai *et al.* (2014)	China	Questionnaire survey	Offsite industrialisation Potential barriers of suing offsite industrialisation Current uptake of offsite in Chinese construction industry Factors to improve offsite uptake	Offsite industrialisation barriers and how to enhance its uptake
(59)	Shahzad *et al.* (2015)	NZ	Case study	Benefits of prefabrication Issues with prefabrication system of construction	Benefits of prefab building system (cost, time and productivity improvements)
(60)	Arashpour *et al.* (2015)	Australia	Case study	Integrating construction process and bottlenecks Process integration with offsite construction Process integration strategies	Optimising process integration with offsite construction Simulation
(61)	Alazzaz and Whyte (2015)	South-west Asia region	Case study	Employee empowerment Offsite construction productivity	linkage between employee empowerment and productivity in offsite construction
(62)	Lessing *et al.* (2015)	Sweden	Literature review Case study	Development of IHB based on studies of literature and three Swedish companies prefabrication and building systems system of constructs for IHB	Conceptual framework covering the areas that constitute IHB

Notes: OSC: offsite construction; OSM: offsite manufacturing; OSP: offsite production; SSM: soft system methodology; IHB: industrialised house building; HCSM: house construction simulation model; YAWL: yet another workflow language; IBS: industrialised building systems; EFC: even-flow-construction, BIM: building information modelling; SDP: sales-driven production; VSM: value stream mapping; HVAC: heating, ventilation and air conditioning; SCM: supply chain management; MMC: modern methods of construction; LCA: lifecycle assessment; DES: discrete event simulation

Table III.

Descriptive analysis	All journals and reports count
No. of articles	*62*
Research context	
Australia	15
UK	14
Sweden	11
Global	7
China	3
US	3
Canada	2
Japan	2
NZ	2
Iran	1
Malaysia	1
Nigeria	1
The Philippines	1
Research method	
Case study	24
Literature review	19
Questionnaire survey	6
Mixed method	4
Conceptual approach	3
Interview survey	3
Focused group	2
Content analysis	1
Design science methodology	1
Research scope (%)	
Offsite concept and definitions	53
Offsite barriers and drivers	27
Lean or agile principles	13
Simulation	7

Table IV. Summary of descriptive statistics based on the classification of Altay and Green (2006)

The scope of the selected offsite studies was covered in four main themes: offsite concept and definitions, offsite drivers and/or barriers, lean or agile and simulation (Table IV). Most of the articles, 53 per cent, explain the offsite concept to provide a knowledge foundation. These articles address OSC and sustainability, affordability, prefabricated technology, productivity, design and production strategies, life cycle analysis, procurement, information flow and resources (Alazzaz and Whyte, 2015; Ganiron and Almarwae, 2014; Kenley, 2014; Kenley *et al.*, 2012; Li *et al.*, 2014; Mostafa *et al.*, 2014b; Rohani *et al.*, 2013). OSC drivers and barriers supporting the adoption of the offsite concept were the major topic discussed, evident in 27 per cent of the articles. However, only 13 per cent of the articles illustrate lean or agile principles as a catalyst for adopting the offsite concept. Notably, none of the articles on offsite drivers and barriers focus on exploring the opportunities of lean and agile principles. These articles mainly focus on identifying or assessing the drivers or barriers of OSC, such as Blismas and Wakefield (2009a, 2009b), Zhai *et al.* (2014b) and Shahzad and Mbachu (2013). Only 7 per cent (4 articles) of the articles focus on applying simulation to the offsite concept. Few of these articles (two out of four) discuss simulation in line with lean or agile concepts (Lu *et al.*, 2011, 2012). The remaining articles focus on simulation using the offsite concept; the process scheduling, visualisation in construction management and process integration with OSC (Arashpour *et al.*, 2015; Dalton *et al.*, 2013; Rohani *et al.*, 2013).

Thematic analysis

As a next step, the articles were coded, analysed and sorted according to four categories: offsite concept, offsite drivers and barriers, lean and agile concepts and simulation. The articles were thoroughly read to enable judgement and categorisation of the articles. A discussion of each category follows.

Offsite construction concept

The first category focuses on the offsite concept definition, processes (including production and construction) and strategies. The first subset of papers discusses the offsite concept by providing the definition, types/forms, patterns and structure of the offsite supply chain, including all stakeholders. Mostafa *et al.* (2014a), for example, discuss the definition of offsite and highlight the offsite supply chain stakeholders, including designers, manufacturers, suppliers, contractors and subcontractors and customers. Boyd *et al.* (2013) define three main forms of OSC, namely, panelised, modular and hybrid.

A second subset defines the offsite production and onsite construction processes. Arashpour *et al.* (2015) focus on optimising the OSC processes and bottlenecks using different integration strategies. Wynn *et al.* (2013) used the Yet Another Workflow Language to enhance the utilisation of OSM through focusing on the construction processes workflow. Johnsson and Meiling (2009) highlight the defect types, measures to correct and occurrences in the OSC. Amir Zavichi *et al.* (2010) discuss methods to achieve mistake proofing to eliminate the defects in construction. Other studies illustrate different aspects of offsite processes, including cores issues, production and construction scheduling, robotic automation and visualisation of construction management (Dalton *et al.*, 2013; Goulding *et al.*, 2015; Rohani *et al.*, 2013).

The third subset of articles addresses the issues of offsite component design. Ganiron and Almarwae (2014) identify the structural characteristics of prefabricated components (e.g. modulus of elasticity, sound insulation and durability). Johnsson and Meiling (2009) mention standard joints, stairwells, wall and floor sections used in their case study. Similarly, Wing and Atkin (2002) highlight the design of the FutureHome, which is based on the kit-of-parts (KOP) approach. They developed the connectors that complement the KOP, which cover structural, assembly and service requirements. In addition, Goulding *et al.* (2013) underline the SMART components (e.g. Keku, Dipple Klick connectors) that offer direct plug and fix capabilities for offsite modules/panels.

The last subset of articles introduces some initiatives to optimise the management the offsite supply chain. For example, Lessing *et al.* (2005, 2015) integrated the supply chain management concept to control the construction processes in industrialised housing. Barlow and Ozaki (2005) address the delivering of mass customised housing, which was mainly based on using a production system. Some studies suggest offsite strategies to match different demand situations and improving procurement (Childerhouse *et al.*, 2000; Mostafa *et al.*, 2014a).

Offsite drivers and barriers

The second category focuses on drivers and barriers of OSC. In this category, many studies have identified and quantified the offsite drivers for, and/or barriers to, traditional building methods. The first subset of the articles addresses the offsite drivers through highlighting its benefits. Recently, Shahzad *et al.* (2015), for example, analysed the cost and time-savings and productivity improvement that could be achieved using prefabrication in New Zealand. Their results show that using prefabrication resulted in 34 and 14 per cent average reduction in completion time and construction costs, respectively. Kolo *et al.* (2014a, 2014b) explored the benefits of OSM in Nigeria. The results of their study reveal that OSM promises benefits, including less wastage on site, faster construction time, quality improvement and reduction in wet trades.

In the UK house building industry, Pan *et al.* (2007) explored the perception of the volume of housebuilders using offsite technologies. Time, cost, quality and productivity were driving the builders to adopt the offsite technologies. In the Loughborough University, a research team developed the Interactive Model for Measuring PRE-assembly and STandardisation to assess the benefits of modular buildings. The benefits were described as cost, time, quality, health and safety, environmental and people (Loughborough University, 2015). Lu and Liska (2008) examined the perceptions of experienced builders in the US construction industry regarding the benefits of offsite techniques. The top three drivers for using offsite were construction time, overall project schedule and effect of incremental weather conditions. Blismas and Wakefield (2009a, 2009b) outline the benefits offered by OSM that fulfil all the main dimensions of sustainable construction in Australia. They assert that OSM has the potential to address the triple bottom line of sustainability. The financial aspects include improving productivity through efficient and simplified processes and a programme which reduces the onsite construction time. The social aspects refer to improving safety and work conditions and stabilising the workforce. The environmental aspects denote creating a cleaner and more efficient working site, high-quality buildings with superior performance and a long building life cycle. Zhai *et al.* (2014b) identify the driving forces behind the use of offsite production (OSP0 in the Chinese residential industry). The environmental factors were the main drivers of OSM, including reduction of construction waste, pollution, disruptions and energy consumption and promotion of the uptake of green building technologies. Their results also identify decreased construction time and certainty of completion time as key drivers for OSP.

Most of the articles that address the offsite drivers identified barriers or challenges. This is because identifying the barriers promotes the offsite concept and assists in realising its benefits. Nadim and Goulding (2011) researched the resistance towards adopting OSM in the construction industry in four European countries: Germany, The Netherlands, Sweden and the UK. The resistance was deeply rooted in unsuccessful past experiences associated with OSM. Another study by Pendlebury and Gibb (2004) provides a list of the constraints of the standardisation and pre-assembly/OSM in the UK construction industry. The constraints covered site, process and procurement. Blismas and Wakefield (2009a, 2009b) identify the four top barriers to OSM in Australia: low levels of skills and knowledge; a combination of cost, value and productivity;

negative customer perception; and freezing the design in its early stages. Zhai *et al.* (2014a) list and rank the largest barriers to OSP in the Chinese residential industry. These barriers include poor integration in the supply chain, inability to freeze the design early, higher demand for site specific and associated logistics for pre-finished element protection and client scepticism and resistance. Lu and Liska (2008) identify the top three challenges of using OSC techniques in the US construction industry; the inability to make changes on site, transportation constraints and limited design options.

Lean or agile principles in the offsite landscape

The third category focuses on lean or agile principles in the offsite concept. The first subset of articles mainly concentrates on explaining lean principles adjustment in construction and highlighting its benefits (e.g. minimising waste and maximising value). The lean concept has been of significant interest to the construction sector since Koskela (1992) presented the TFV theory in construction. The theory conceptualised construction in three ways; the transformation of materials into building structures, the flow of materials and information through various building processes and value generation and creation for customers through cutting out value loss. Further research works have been founded on Koskela's work to examine the lean principles in construction.

Pasquire and Connolly (2002) report on the improvements made when integrating lean production principles at a manufacturing centre for heating, ventilating and air conditioning (HVAC) modules. These improvements included reduction of labour needed and time, cost savings and lower skill level required compared to *in situ* assembly. Höök and Stehn (2008) discuss the development of a lean production culture in Swedish industrialised housing. They stress that lean principle applicability is influenced by a production culture that is similar to the factory production of industrialised housing. Eriksson's (2010) study was targeted towards increasing the understanding of lean-related aspects implementation in a construction project and how they affect the supply chain. These aspects included waste reduction, process focus in production planning and control, continuous improvements and end customer focus. Amir Zavichi *et al.* (2010) define lean construction as the relocation of lean production philosophy, which is a series of cultural and technical changes, into the construction domain after its successful implementation in the Toyota Motor Company. Their study investigated adopting one of the lean practices, mistake proofing. It is a robust tool which prevents unplanned error in work and prevents workers from performing incorrectly. This concept provides great opportunities for bringing quality into project delivery. It also frees workers from tedious recurring jobs and increases safety at construction sites.

The second subset of articles targeted both lean and agile principles in construction. The theory behind applying agile principles is that lean principles are suitable for stable conditions (stable volume demand) (Purvis *et al.*, 2014), whereas current market completion is characterised by uncertainties (e.g. demand variety and site conditions). Therefore, agile principles can complement lean principles to respond proactively to any of these uncertainties (Daneshgari, 2010; Sertyesilisik, 2014). Childerhouse *et al.* (2000) state that agile principles are required as the demand for housing is unpredictable. They explain the principles of lean and agile for managing the housing supply chain in the UK. Lu *et al.* (2011) propose a lean-agile model for Swedish homebuilders using value stream mapping. The model focuses on balancing responsiveness and stability of the production system in the offsite factory. Mostafa *et al.* (2014a) propose a synergistic supply chain to increase OSM uptake in Australia. Their suggested supply chain establishes four strategies to integrate lean and agile using the customer order decoupling point (CODP). The strategies are build-to-stock (BTS), assemble-to-order, design-to-order (DTO) and self-build house. They argue that these strategies could balance the trade-off between the house the customer demands and the capacity of the house builder.

Simulation in the offsite landscape

The fourth category concentrated on using simulation in the offsite concept. In this category, a few studies (4 out of 59) demonstrated the application of simulation in the offsite supply chain. Simulation has mainly been used in specific areas, including planning and scheduling of workers and operational processes. Al-Bazi and Dawood (2012) applied simulation in planning and scheduling of employee allocation in offsite precast production operations. They used discrete event simulation (DES) to analyse several scenarios and evaluate the optimum allocation of each set of crews of workers. Arashpour *et al.* (2015) applied simulation to create multi-skilled resources in OSC through comparing cross-training strategies. Lu *et al.* (2012) built a hierarchical DES model for industrialised building processes. The model targeted the detailed operational processes for house components to enrich information, including cost and delivery time. Rohani *et al.* (2013) underlined the need for using visual simulation for efficient management of onsite planning. They stress that simulation allows building organisations to develop and test different scenarios of building environments to achieve the requirements of the building owners, and subsequently the intended occupants, before construction. Dalton *et al.* (2013) designed a simulation model for examining the relationship between the day-to-day operational variation effects on the volume builder's efficiency. The simulation model explained the behaviour of the construction system used by the builders. As a result, they identified the main factors (i.e. variations in work times and constrained resources) that cause instability of the system. The simulation was used to evaluate and validate a proposed lean-agile model for industrialised building (Lu *et al.*, 2011). Their research reveals that simulation can provide empirical evidence and quantitative analyses for evaluation of different scenarios in industrialised house building.

Discussion

Development of lean and agile principles from manufacturing to house building

The construction industry challenges, such as cost and time overrun, have forced industry practitioners and scholars to research and learn from other sectors such as manufacturing. Koskela (1992) broadens an understanding of construction as a production process using theTFV theory. Adopting manufacturing principles/methods in construction faces some challenges, which mainly around the different attributes between manufacturing and construction industries. These attributes include product type, processes, supply chain, business processes and end-user involvement. However, Hong-Minh *et al.* (2001) state that construction is similar or equivalent to manufacturing regarding processes. This means that it is important to study and understand the differences between construction and manufacturing from a process perspective. This leads to questioning whether construction uses/includes manufacturing/industrial processes. The answer to this question can be extracted from the construction industry history. Gann (2010) mentions that traditional construction techniques developed into industrialised techniques in 1850. This industrialisation stage affected construction components, material and methods. Therefore, Court *et al.* (2009) hypothesise that the construction system can incorporate manufacturing methods such as modular assembly, postponement, reflective manufacturing, pulse-driven scheduling and ABC parts classification.

Industrialisation of construction adopts the idea of simplifying and reducing onsite construction activities to be undertaken in OSM facilities (Koskela, 2003). Gann (1996) highlights the three most important principles of industrialisation: standardisation, prefabrication and systems building. The structure of the industrialised construction supply chain (offsite and onsite working locations) facilitates transfer of some manufacturing principles, such as lean and agile. These principles suggest managing the two sites effectively (Ballard and Tommelein, 2012; Blismas, 2007; Pasquire, 2012; Sacks *et al.*, 2010; Tommelein, 2015). Lean and agile principles are a collection of tools/techniques which apply to effective and efficient usage of resources, reduction in waste, variation and rework and increased quality and value (Sertyesilisik, 2014). Lean tools (i.e. 5S, pull planning, continuous improvement and last planner system) target all forms of waste in any process (Ballard, 2000; Mostafa *et al.*, 2013). Agile techniques concern many features of an organisation, including processes, people, management and organisational structures, vendor relationships and business strategies. Agile refers to use of resources and people that can be changed, or reconfigured, quickly and easily for coping with variability and uncertainty (Owen *et al.*, 2006). Agile consists of some tools such as virtual teams, communication and visualisations tools such as computer-aided design/computer-aided manufacture (CAD/CAM) (Owen *et al.*, 2006; Sertyesilisik, 2014).

The house building sector is part of the construction industry that fits under residential building. It can be seen through the literature review and research analysis sections in this paper that house building techniques in different contexts share the industrialised/offsite experience. To successfully transform lean and agile principles, it is important to understand house building features and the similarities between house building and manufacturing industries. The significant differences between manufacturing and house building should also be acknowledged. Lean construction practices include the pull system, visual management, continuous improvement, Last Planner System®, 5S process, reduced batch size, standardised work structuring and error proofing (Abdelhamid *et al.*, 2008; Sacks *et al.*, 2010). The initiative of agile construction was set up in direct response to the Latham report to reduce cost and enhance productivity in the UK construction industry (Latham, 1994). The benchmarking process was suggested to realise these targets through continuously measuring and comparing construction organisations' performance against world construction leaders to improve performance (Lee, 2003). Agile construction exemplifies the characteristics of visibility, responsiveness, productivity and profitability. Agile comprises some management tools such as virtual enterprise, concurrent engineering and information technology (i.e. CAD/CAM) (Daneshgari, 2009).

As previously stated, integration of lean and agile principles is the best solution to answer all the production issues in world-class market competition (Agarwal *et al.*, 2006), and combining them within the whole supply chain can be accomplished by using the DP and leagility. Normally, the DP separates the leagile supply chain into lean in the upstream and agile in the downstream (Sackett *et al.*, 1997; Mason-Jones and Towill, 1999). For competition, Christopher and Towill (2000) indicate that supply chains must be in touch with market demand changes, which can be divided into three critical dimensions; variety, variability (or predictability) and volume.

Current use of lean and agile principles in offsite landscape

Several studies have confirmed the benefits of using offsite concept (Blismas and Wakefield, 2009a, 2009b; Boyd *et al.*, 2013; Hampson and Brandon, 2004). The uptake of OSM in the Australian house building context is limited compared to OSM in other developed countries such as the UK and the USA. The research efforts related to OSM in Australia have focused on the drivers and barriers to implementing OSM. The first main driver for OSM is the shortage of skilled tradespeople to undertake onsite work. The second driver is related to simplification of the onsite process to reduce the construction time onsite. Environmental sustainability advantages are considered as the third driver for adopting OSM. The other drivers include a reduction of the OHS risks, improving the quality of the construction products and better work conditions. The constraints of using OSM in Australia include a low level of industrial knowledge of OSM, a combination of cost, value and productivity, negative customer perception of prefabricated products and longer lead times and freezing the design in the early stages (Blismas and Wakefield, 2009a, 2009b).

The application of lean and agile concepts seems minimal in the Australian house building sector. The development of OSM in house building lacks a clear description of the concept and its technical, organisational and process-related issues. To achieve an efficient building process, OSM must be based on a holistic (supply chain) view. However, this could lead to consequences for the structure of the building process in changes of organisational and production-related conditions. The general house building process is not designed to handle the whole process as a supply chain. All the drivers and barriers of OSM in Australia significant to a successful OSM application are included in this paper. Moreover, lean and agile integration is considered as a new approach to overcome OSM barriers and increase the opportunities for OSM in the future. As stated earlier, according to Naim and Barlow (2003), there are similarities between house building and the production of PCs. Although there is little to differentiate the products, it is still necessary to customise the product to meet the customer demands. Gann (1996) argues that the house building industry could learn from the manufacturing industry. Therefore, it is important to understand house building features and the similarities with the manufacturing industry (Table I).

Product and process design in manufacturing are usually undertaken by the same company, whereas in house building, different companies typically perform design and/or construction. Barlow (1999) states that the housing production methods set the industry somewhere between craft production and mass production. The ability to capture customer demands will enable the organisation to deliver the required products. A prefabricated house can be decomposed into core elements: the foundations, the roof, the fit-out and the services. Each of these elements consists of one or more components.

Thus, the house is an assembly consisting of sub-elements and components that are connected. To accomplish this, there are a number of different actors in the house building supply chain, including developers, builders, contractors, sub-contractors and suppliers (Naim and Barlow, 2003). House building supply chain could actuate through delivering standardised components until the DP and then assemble according to customer demand (see Figure 1). The objective of an agile approach is to ensure that house builders can respond to customer requirements during the conceptualisation phases of a project and accelerate decisions during its recognition phases. Some attempts have been made to develop tools for capturing customer requirements more efficiently using new techniques such as quality function deployment (Barlow, 1999). Agile production is partly reliant on the introduction of lean production techniques.

Development of offsite themes within the architecture, engineering and construction industry

The SLR revealed the main themes of the offsite concept in different contexts that are related to the aim and objective of this study. These themes are the offsite concept and definitions, offsite drivers and/or barriers, lean and agile principles and simulation. The themes are considered as necessary components for adopting offsite practices in the architecture, engineering and construction (AEC) industry. The development and distribution of these themes over time are shown in Figure 4. The name of each theme captures the significant meaning and the focus of the theme.

The offsite concept and definitions found in Gann (1996) discuss Japanese industrialised housing production (Figure 4). Adopting an offsite concept requires structural changes in the AEC supply chain. This is due to using two working locations (offsite and onsite) simultaneously (Johnsson, 2013). In addition, OSC changes the way people in the AEC industry work in terms of the process and product. Therefore, some studies were based on the understanding of manufacturing principles and recommended lean and agile techniques

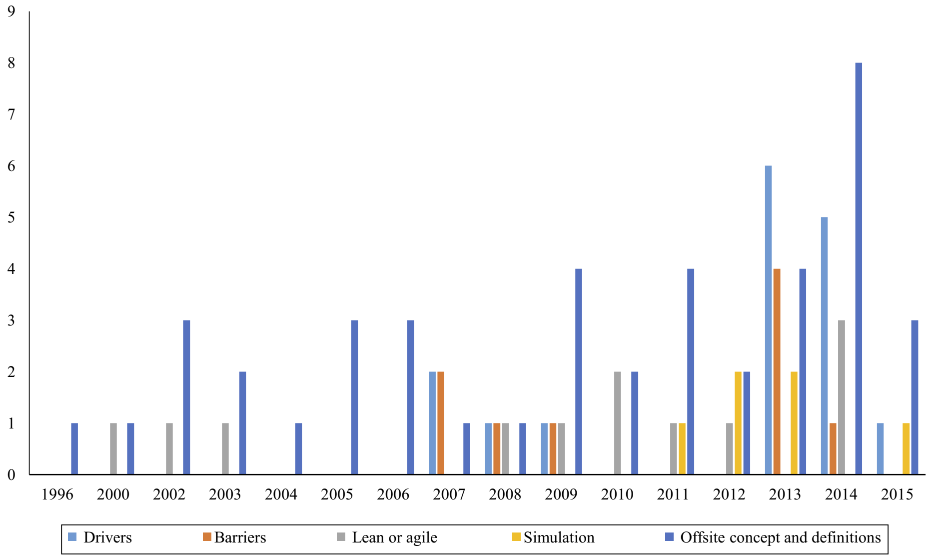

Figure 4.
Offsite themes distribution within the AEC industry

to manage the entire offsite supply chain (Childerhouse *et al.*, 2000; Naim and Barlow, 2003; Pasquire and Connolly, 2002; Partnership for Advancing Technology in Housing, 2002). Nonetheless, transformation towards offsite was limited, because of the constraints of a fragmented AEC industry. As a result, a plethora of studies address the barriers and drivers of OSC in different contexts, such as Pan *et al.* (2007); Goulding *et al.* (2014) and Arif and Pannell (2013) in the UK; Blismas (2007) and Blismas and Wakefield (2009a, 2009b) in Australia; Lu and Liska (2008) in the USA; Shahzad and Mbachu (2013) in New Zealand; and Zhai *et al.* (2014a, 2014b) in China.

Studying offsite barriers could be considered as the basis for enhancing the uptake of the offsite concept within the AEC industry. Most of these previously mentioned researchers believe that when offsite drivers outweigh the constraints, the uptake of OSC would be expected to be greater within the industry. Most of the barriers identified in these studies were found to be similar. For example, Blismas and Wakefield (2009a, 2009b) conclude that the drivers and barriers of OSC in Australia are considerably the same as those identified in the UK and the USA. The main barriers were the lack of manufacturing knowledge, negative customer perception about prefabricated products, longer lead times and freezing the design in early stages and poor integration in the supply chain (Blismas and Wakefield, 2009a, 2009b; Lu and Liska, 2008; Nadim and Goulding, 2011; Zhai *et al.*, 2014a). Overcoming the offsite barriers depends on an understanding of the principles underpinning manufacturing and appreciating the pitfalls that come with the defragmented nature of the AEC industry.

Several streams of research have focused on balancing between an understanding of the manufacturing perspectives of OSC and considering the nature of the construction industry (Azambuja and O'Brien, 2009; Ballard and Arbulu, 2004; Blismas, 2007; Manley *et al.*, 2009; Manufactured Housing Research Alliance, 2003; Partnership for Advancing Technology in Housing, 2002; Vidalakis *et al.*, 2013; Vrijhoef and Koskela, 2000). These studies recommend using lean and agile principles to mitigate OSC barriers. Lean and agile principles aim to give more control over value specification and demand while designing the process to eliminate waste (non-value added activities), optimise efficiency by empowering the workforce and continuous improvement. Lean and agile principles can be diffused to several areas within the OSC system. Lean can be integrated into areas such as:

- *Effective scheduling, for example, Last Planner system*: This facilitates keeping track of the work programme and workers. This is especially appropriate for construction activities, as crews move among sites.
- *Quality management for quality at the source in the fabrication factories (building components or modules) and the construction site*: This requires mapping of all activities to define the quality shield, which is a set of controls needed to ensure product conformance. These controls translate into specifications to be enforced by the workforce in the two working locations.
- *Continuous improvement*: This is improvement for constant efforts to improve products, services or processes.
- *The Kanban system*: This is a material flow control technique which can be applied to particular types of materials (consumables and power tools). The system is based on the main storage and supply components, the collection of vehicles (external and internal to bring the materials from supplier to job site),

supplier Kanban, satellite stores (onsite locations that get products from the marketplace) and an inventory management system (Abdelhamid *et al.*, 2008; Ballard and Tommelein, 2012; Paez *et al.*, 2005; Sacks *et al.*, 2010; Sertyesilisik, 2014; Tommelein, 2015).

The agile principles that can be implemented in the construction area include:

- *Virtual enterprise (VE)*: This is a temporary network among organisations with a similar supply chain with the purpose of delivering a service or product. In general, an organisation may not be able to respond quickly to the changes in customer demand. Therefore, VE is a modular technique that an organisation employs to increase its agility.
- *Concurrent Engineering (CE)*: This is a systematic approach in integrated product development to respond to customer expectations. CE focuses on the optimisation and distribution of an organisation's resources in the design and development stages to ensure effective product development process. CE includes design for manufacture and assembly to enhance the manufacturability and assembly of the building components or modules.
- *Software and decision support systems for product design, production planning and control, and data management*. This includes Manufacturing Resource Planning II and enterprise resource planning systems (Demir *et al.*, 2012; Sertyesilisik, 2014; Sharifi and Zhang, 2001).

The SLR also revealed that using simulation in OSC was undertaken by Lu *et al.* (2011) and was associated with lean and agile principles. The authors used simulation to test their suggested lean-agile model for the Swedish industrialised housing industry, because lean and agile principles mainly focus on the resolution of design and operational issues in any manufacturing system. Redesigning the system, that is, structural variations, cannot be tested using lean or agile principles. This is the case for OSC, as it changes the entire traditional AEC supply chain. The structural changes include using/managing two working sites concurrently. Likewise, it changes the way construction work is done in terms of process and product. Therefore, simulation is capable of supporting the offsite supply chain, finding optimum structural and functional designs that meet manufacturing (offsite) and construction operations (onsite) requirements before real implementation. Simulation models evaluate the effects of variation and validating the effects of proposed changes, as well as identifying other possible improvements and assessing the interaction effects between system components (Marvel and Standridge, 2009). Applying simulation could supplement the integration of lean and agile principles within the offsite supply chain. Simulation also can be used for:

- identifying problems within the entire offsite system (fabrication facility and construction site);
- training workers in the way processes operate; and
- testing what-if scenarios for process improvement in the offsite supply chain. These scenarios could be strategies for integrating lean and agile principles, such as build-to-stock, design-to-order and engineer-to-order strategies, as discussed in Johnsson (2013) and Mostafa *et al.* (2014a).

Offsite themes connection

From the thematic analysis, the offsite concept and definition was founded as the common ground for other themes, as demonstrated in Figure 5. A plethora of research explains the offsite types (e.g. modular, panel), processes (manufacturing and construction), offsite components design (i.e. connectors and structural components) and supply chain strategies (Gibb, 1999; Goulding *et al.*, 2013; Johnsson and Meiling, 2009; Lu *et al.*, 2011; Mostafa *et al.*, 2014a). It can be concluded from Table IV that different research streams have emerged from the offsite concept to other themes: drivers and/or barriers, lean and agile and simulation. This is illustrated by the solid lines in Figure 5. It means that there is a strong relation between the offsite concept and definitions and the other four themes. This relation is based on the number of articles addressed the concept with each theme. It was discovered that seven articles focused on the offsite concept and its drivers, such as Goulding *et al.* (2014), six articles focused on the barriers, including Alazzaz and Whyte (2014), and 11 articles focused on the barriers and drivers (Lu and Liska, 2008; Zhai *et al.*, 2014a). Nine articles were covered the lean and agile principles within offsite concept, including Naim and Barlow (2003), Lu *et al.* (2012) and Mostafa *et al.* (2014a).

Only four articles addressed different simulation methods in the offsite concept. Arashpour *et al.* (2015) and Al-Bazi and Dawood (2012) applied DES in the planning and scheduling of worker allocations in the offsite concept. Dalton *et al.* (2013) used Simul8 to analyse the operational variations on the volume builders' efficiency. Lu *et al.* (2011) used CYCLONE and Simphony.net to assess the leagile model for industrialised house building. A limited number of articles addressed the application of lean and agile principles within OSC using simulation. Two articles established a connection between lean and agile principles with simulation, including Lu *et al.* (2011), who tested the lean-agile model using simulation. The simulation assisted in validating and evaluating the responsiveness and stability of the offsite factory. Lu *et al.* (2012) suggest the DES model to integrate building information modelling (BIM) and lean-agile principle configuration design for industrialised building processes. They argue that simulation could provide a balanced trade-off and value all stakeholders involved in the industrialised housing supply chain.

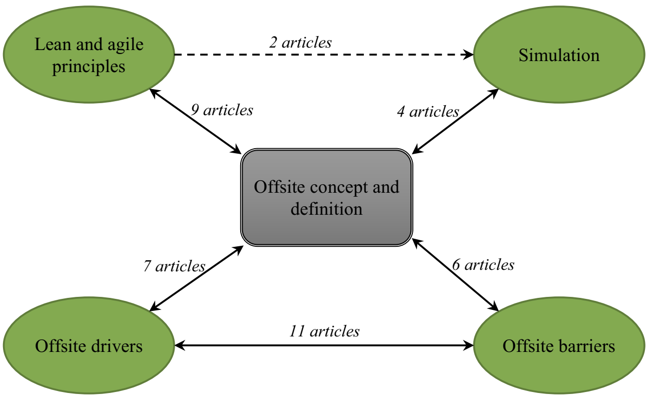

Figure 5. Offsite themes association

Conceptual research roadmap for offsite construction uptake

In examining the identified OSC research themes, future research directions can be further derived based on what has been done and what remains to be undertaken in the OSC landscape. According to the research results, this study hypothesised that OSC uptake is inseparably linked to the OSC concept and definitions, drivers and/or barriers, lean and agile manufacturing principles and simulation (Figure 6).

The offsite themes demonstrated in Figure 6 show a significant and tangible means of enhancing the future of the offsite concept in the AEC industry. The future landscape of offsite adoption could be influenced by the degree of understanding and the dynamic of each theme. Goulding *et al.* (2014) point out that offsite drivers and barriers are dynamic. This means that identifying and evaluating barriers/drivers is not sufficient for improving offsite adoption. It must be associated with assessing the level and dynamism of OSC barriers. Therefore, it is important to attempt to try and predict some of these relationships through implementation within OSC in any context. For example, the roadmap in Figure 6 highlights the interface between lean and agile principles and offsite barriers. A technique such as quality function deployment (QFD) can be used to evaluate the association between each barrier and lean and agile tools. The QFD matrix consists of the what is (offsite barriers) and the how is (lean and agile tools/practices). One of the offsite barriers is freezing the design at early stages of the house building project. This barrier affects the adoption of the offsite concept from the client and builder perspective. Usually, freezing the design occurs, because once the component/module designs are completed, the design is passed to the offsite factory for the production process. Similarly, any attempt to change the design is based on the limitations of the available designs of houses, components and modules. However, using agile tools, such as concurrent engineering, might overcome this barrier by providing more integrated designs or using visualisation systems (e.g. CAD). This allows clients more flexibility

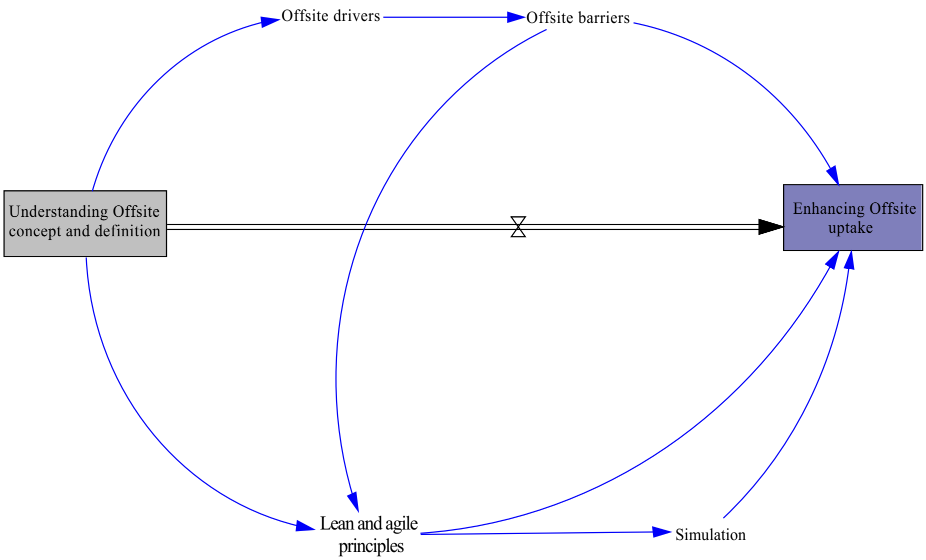

Figure 6. Future research roadmap for enhancing offsite uptake

and customisation over the design stage. As a result, builders will be motivated to adopt the offsite technique.

The growing emphasis on construction customisation is an opportunity to link lean and agile principles and simulation in OSC. Lean and agile principles can be integrated into the offsite supply chain using the CODP, the point where the client order enters the supply chain. This means more flexibility and customisation for clients. Each point of intervention can be considered as a strategy of merging lean and agile principles. Each strategy gives a different degree of customisation. For example, Mostafa *et al.* (2014a) mention that when a customer order enters the offsite supply chain at the design stage, customers have the opportunity to change the design of the offsite components, a strategy known as DTO. Another strategy is BTS, where clients have limited flexibility as the building is completed. They can only choose one building from the stock based on location, design and cost considerations. Each of these strategies requires a different structure of the available facilities of any builder. Simulation is capable of testing the effectiveness of these structural changes of each strategy regarding cost and completion time.

Goulding *et al.* (2014) mention that DES provides exclusive insights into probability generation for predicting outcomes of multiple what-if scenarios. This means that DES can provide high-level process visibility for the offsite concept under each different scenario generated. DES will support the decision-making process in any construction company to enable choice of various forms of structural changes and strategies based on a complete process review analysis. Similarly, simulation mimics the behaviour of the real system under some assumptions using a virtual environment, such computer simulation software (e.g. Arena®, Simul8 and ProModel). This will supplement the application of lean and agile principles to identify and map any variation in the process. This supplementation complements the traditional value stream mapping in lean principles, which is usually static, making it more dynamic (Marvel and Standridge, 2009). Furthermore, the simulation will support how agile teams operate and the benefits of an agile approach. This will help develop improved client satisfaction levels and, in turn, help in strengthening the demand.

Proposed framework for integrating lean and agile within offsite supply chain using simulation

After identifying the gap in knowledge, this paper suggests a research framework for using lean and agile principles in the offsite, landscape as presented in Figure 7. The framework is built upon the background studies and literature survey conducted in the methodology section. The suggested research framework contained two stages:

(1) conceptual and simulation models description; and
(2) verification, validation and reporting of results.

The research framework started from the findings of the previous research design for gaining better understanding the research area and developing the research objective and methodologies.

Stage one: conceptual and simulation model description

This stage focuses on describing ongoing development and establishes a framework for applying lean and agile principles to the OSC supply chain. It is important to conduct the

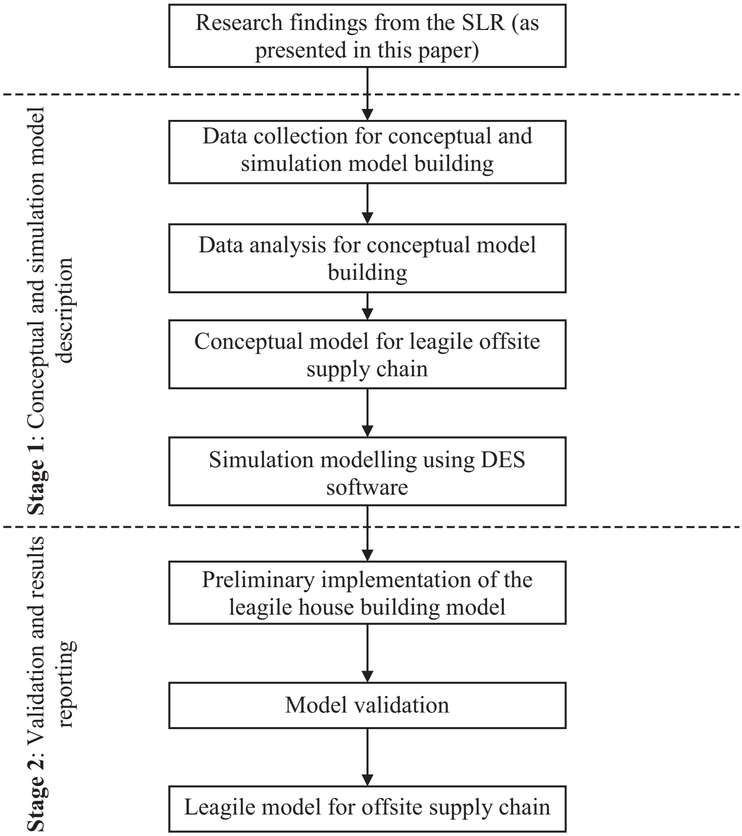

Figure 7.
Proposed research framework for integrating lean and agile integration with offsite concept in the lens of simulation

study with the organisations currently working in this area (manufacturers, designers, builders or engineering). Stage one consists of data collection to identify the onsite and offsite process parameters for generating practical, conceptual and simulation models. It can be fruitful to apply mixed methods to collect data on the offsite processes and parameters. The expected output of this data collection process will lead to establishing the conceptual and simulation models.

Conceptual model description

The conceptual model is the mathematical/logical/verbal representation of the problem entity developed for a particular study (Sargent, 2013). The model is an important part of an efficient simulation process. It formulates the initial structure for further development of the simulation model. The model visually describes the interaction and flow of the entities in the simulation environment. The conceptual model of an offsite supply chain contains information about the house building stages (e.g. design and engineering, procurement and manufacturing), material and information flows and model parameters (e.g. time distributions and resources for each process). The structure of the conceptual model should start with depicting and analysing the current process of building the house. The conceptual model consists of two components, the offsite factory and the building site (as shown in Figure 1). Factory fabrication includes all processes for producing building elements such as walls and floor panels and roof systems. The construction work on the site is divided into a first fix and second fix (Marshall *et al.*, 2013). The first fix comprises all construction processes from foundations to provisions on the walls. The second fix embraces all processes to complete the building, including finishing joinery, plumbing and electrical components.

Within the conceptual model, the offsite process begins with designing the building components according to the client's demand or a builder catalogue. CAD or BIM could be used to model, visualise and analyse the house design elements in the three-dimensional environment. This allows elimination of inconsistent design concepts and more flexibility to achieve customer demands (Greenwald, 2013). The engineers and architects analyse the structural components and elements to ensure that every component from HVAC, electric and plumbing is checked and optimised for fabrication. The design information is referred to the factory for producing the house elements. Selective materials such as timber and steel are procured from trusted suppliers to meet quality control. In the offsite factory, the production process of the elements and trades is carried out in a controlled environment protected from any weather challenges. The wall panels are cut-out for openings of windows and doors. Subsequently, insulation and electrical systems are completed. At the same time, the floor panels are produced, and plumbing works for the wet rooms (bathroom, laundry and kitchen) are completed. After production is complete, wall and floor panels and roof elements are easily transported to be assembled. The foundation is completed at the construction site in advance and is ready for the assembly process to begin. The work on site is carried out to install the building component and modules with less employees (e.g. fixers and logistics team). Therefore, the process reduces the risks of onsite accidents, improves accuracy and speeds up construction time. Roof trusses and sheeting are assembled in special configurations and then transferred to cover the house. The next phase is adaptability of the house to be ready for occupation through exterior and interior finishes.

Simulation model description

Simulation is an experiment of the conceptual model conducted in a virtual environment using a computer (Sargent, 2013). It has been used for modelling and analysing construction processes (Martinez, 2010). It has been used in planning and designing the construction processes (Kamat and Martinez, 2001). The simulation model describes the behaviour of the real-world system in a mathematical and/or logical form. The model considers constraints of the real systems to perform each process, including available resources and managerial decisions taken during the process. The computer-based simulation techniques, such as DES, are used to build, test and optimise the model (Heesom and Mahdjoubi, 2004). DES is used for modelling an offsite structural steel fabrication of a beam bridge project. Simulation is used to assess different fabrication plans and achieves a 10 per cent decrease in the completion time (Alvanchi *et al.*, 2012). The computer simulation packages provide quickness in developing and evaluating the model. Various DES software packages have been successfully used in construction management, including CYCLONE, COOPS and Arena® (Arashpour *et al.*, 2015; AbouRizk, 2010; Moradi *et al.*, 2015; Sadeghi *et al.*, 2013; Shi, 2002).

Stage two: verification, validation and results reporting
This stage aims to verify and validate the simulation model, which is a substitute for experimentation within the real system (existing or proposed). Therefore, if the model is not close to the real system, any conclusions based on the model may result in costly decisions (Law and McComas, 2001). Model verification is the next step in developing the simulation model. It shows that the simulation programme expectedly performs to provide a correct logical representation of the model. On the other hand, validation establishes that the model behaves in a manner that reasonably represents the real system (Sargent, 2013). Verification and validation help to assure that models and simulations are correct and reliable (Pace, 2004). Verification can be viewed as a rigorous debugging with one eye on the model and the other eye on the model requirements. Besides simply debugging of any model development errors, verification examines whether the programme code reflects the description found in the conceptual model. Furthermore, one of the verification goals is to show that all parts of the model work, both independently and collectively, and use the right data at the right time. Regarding validity, Law and McComas (2001) argue that a model is only valid for a particular application if its logic is correct and if it uses appropriate data. Validation is concerned with the model adequately representing the real world system, model generating behavioural data characteristic of a real system and confidence in the model's results.

Figure 8 explains the relationship between the actual building system and the simulation system for developing the conceptual and simulation models. The projection of this relationship was developed and based on the study of Pace (2004, p. 165). Moreover, Figure 8 demonstrates the validation of the conceptual and simulation model, as well as the verification simulation model. In this paper, the seven-step approach is suggested to conduct a successful simulation study within the OSC domain. Moreover, ten techniques, as suggested by Law and McComas (2001, p. 23), are to be applied for developing the validity and verification of the simulation model, as shown in Figure 9.

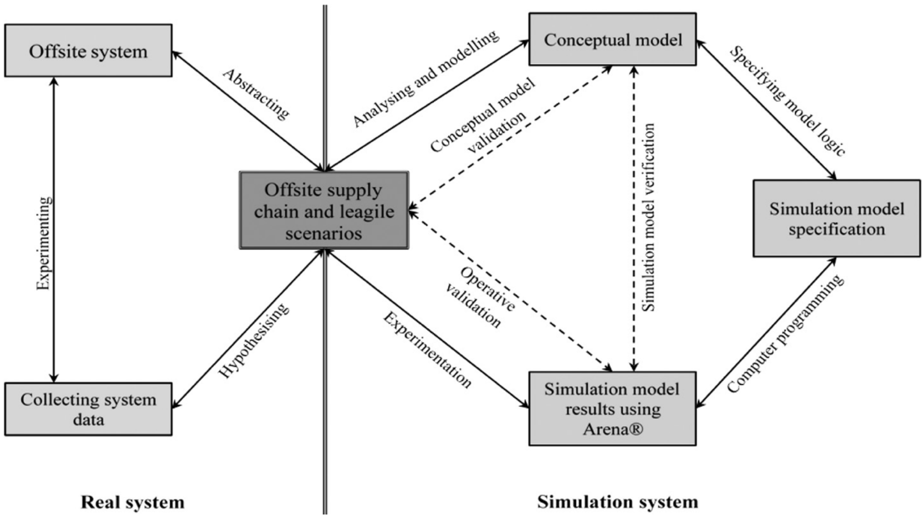

Figure 8.
Real and simulation worlds' relationship for developing a simplified modelling process

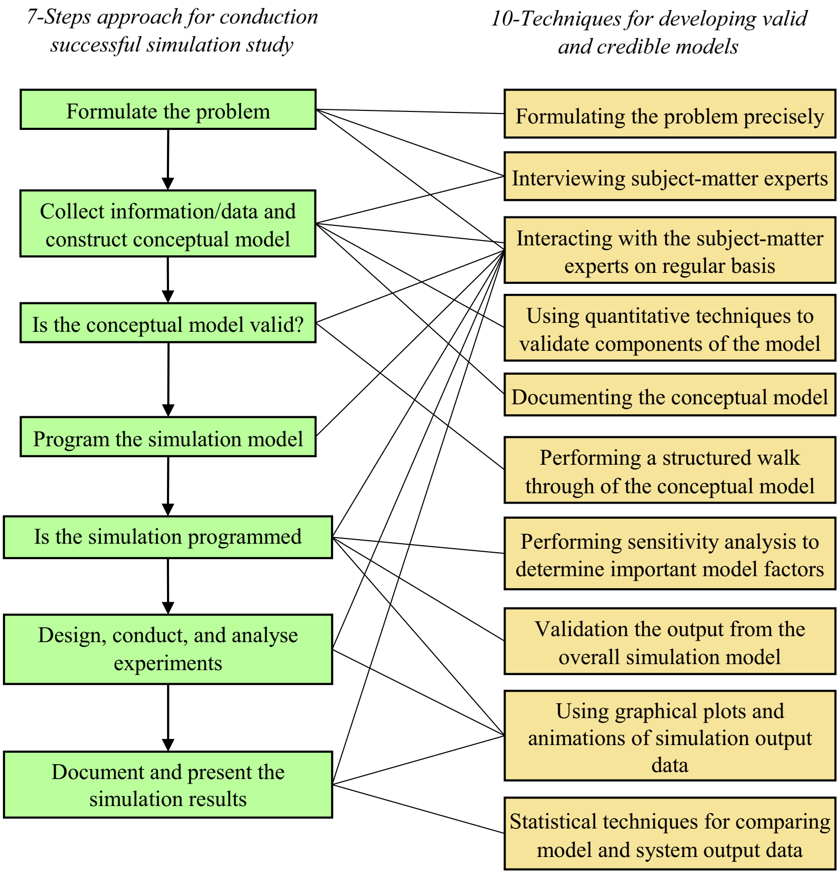

Figure 9.
Relationship between seven-step approach and ten techniques for conducting successful simulation

The proposed framework in this paper does not take on a detailed explanation of model verification and validation, as they have been fully addressed in other studies (Balci, 1994; Pace, 2004; Sargent, 2005, 2013; Shi, 2001, 2002). Therefore, the proposed framework focuses mainly on describing the conceptual and simulation models for the OSC supply chain.

Conclusion

This study conducted an SLR with the aim of analysing and integrating existing knowledge from various bodies of literature on the OSC concept and lean and agile principles. The screening of the literature resulted in 62 related articles published between 1992 and 2015 (Table IV). Data were extracted from these articles and amalgamated for attaining the research aim and objectives. Descriptive and thematic analyses were used in the data analysis process. The analyses identified the related offsite research studies that contributed to developing the offsite concept in different construction contexts. Each of the 62 articles was examined for achieving the aim and objectives of this study, the method of data collection and offsite themes covered. The results of the analyses revealed that most of the articles provided information on the offsite concept and its definitions (53 per cent) and offsite barriers and/or drivers (27 per cent). However, it was noted that limited attention was paid to lean and agile principles (13 per cent) and simulation (7 per cent) integration within the OSC concept (Table IV).

The SLR has some implications for research and practice in the OSM/OSC area. For offsite research, the SLR shows a clear need for further research studies that can be focused on the research gaps related to:

- associating OSC barriers and lean and agile principles;
- relating lean and agile principles and simulation within the OSC supply chain;
- associating improvement in OSC uptake with OSC themes; and
- future implementation frameworks for integrating lean and agile principles within the OSC supply chain.

For the OSC practice, the SLR showed:

- the significance of identifying the main themes and components and its influence on OSC uptake; and
- integrating lean and agile principles and simulation to find and evaluate suitable scenarios of configuration changes to use offsite.

Therefore, this paper can be considered as a solid base for future research in the offsite landscape in different construction contexts. As opined by Tarraco (2005), the identified six areas emergent and illustrated in Figure 6 are significant and tangible and enhance the future of the offsite concept in the AEC industry and would form the basis for posing proactive questions, thus giving directions for future research. Second, the proposed framework illustrated in Figure 7 could enhance and contribute to new ways of thinking about the subject matter under investigation, namely, that of integrating lean and agile principles within OSM/OSC. As suggested by Rocco and Plakhotnik (2009, p. 122), the goal of conceptual frameworks is to categorise and describe concepts relevant to the study and map relationships among them. Accordingly, future research can use the identified six themes in this study and use them as the foundation for further empirical studies. These could explore and map the relationships amongst the identified themes. The SLR used in this research contributes to the scientific community of OSC through underlining its main themes and suggesting future avenues for empirical research in the offsite area.

Regarding the limitations of this study, the authors acknowledge the drawbacks of the SLR methodology (Denyer and Tranfield, 2009), especially those concerning the literature sampling criteria and analysis. Moreover, extensive empirical research is required to test and validate the proposed research framework. Future research should start from identifying offsite barriers and then collect data to explore lean and agile principles before testing the research roadmap and the applicability of the suggested framework. Furthermore, it is necessary to develop different strategies for lean and agile integration using simulation. Therefore, the authors believe that this study contributes to the expansion of OSC knowledge and sets the ground for future research initiatives.

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