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Richmond Juvenile Ehwi, Kwadwo Oti-Sarpong, Reyhaneh Shojaei & Gemma Burgess


To link to this article: https://doi.org/10.1080/01446193.2021.2007537

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Published online: 05 Dec 2021.

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Richmond Juvenile Ehwi, Kwadwo Oti-Sarpong, Reyhaneh Shojaei and Gemma Burgess

Cambridge Centre for Housing and Planning Research, Department of Land Economy, University of Cambridge, 19 Silver Street, Cambridge CB3 9EP, United Kingdom; Centre for Digital Built Britain, University of Cambridge, 21 JJ Thomson Avenue, Cambridge CB3 0FA, United Kingdom

ABSTRACT
Debates regarding research methodologies in construction, engineering and management (CEM) literature are long-standing. However, in the growing literature on offsite manufacturing (OSM), such debates are lacking and some studies conflate different components of research methodologies such as research design, methods, data sources, data types, and analytical techniques. This study examines the components of research methodologies reported in the OSM literature and how they compare with the established relationships between the key components of research methodologies. We analyse 74 articles on OSM sampled from 26 journals and find that quantitative methods, case studies, primary data, bibliometric database and modelling are the most preferred methodological approaches. The methodological components reported also cohere with established relationships between components of research methodology, other than the relationship between research methods and data sources. The findings reveal a growing hybridisation of research designs, data sources and analytical techniques, which suggests that methodological plurality is emerging in the OSM literature. This re-echoes concerns regarding the dominance of quantitative methods and the limited use of theory in CEM research, and consequently highlights the need for diversity in methodologies to expand knowledge boundaries.

Background
Methodological debates in construction, engineering and management (CEM) research are long-standing (Dainty 2008). Seymour & Rooke’s (1995) critique of the dominance of the rationalistic paradigm in CEM research and Runeson’s (1997) defence of quantitative approaches reinvigorated the methodological debates in CEM. Since then, CEM scholars have shown interest in taking stock of the methodologies employed in their field with a view to informing a more pluralistic debate. For example, Dainty (2008) examined 107 publications in Construction Management and Economics (CME) and found that 71%, 8.4%, 11.2% and 9.4% employed quantitative, qualitative, mixed and review methods respectively. This informed the conclusion that there is an ‘entrenched adherence to positivism and a reluctance to adopt radical qualitative methods which could provide richer insights into industry practice’ (p. 10). Agyekum-Mensah et al. (2020) also reviewed 4,166 publications in CME, Journal of Construction Engineering and Management (JCEM), Association of Researchers in Construction Management (ARCOM) proceedings and Engineering Construction and Architectural Management (ECAM) between 2000 and 2017 and found that 41.4% applied qualitative, 33% quantitative and 9.6% mixed methods. They concluded that methodological debates of the 1990s have contributed to a shift in CEM research methodological pluralism (p. 11). Others have gone beyond the paradigm debate to criticize the lack of social theory (Schweber 2015) and the limited number of theoretical contributions in construction research (Betts & Lansley 1993). For example, Betts & Lansley’s (1993) review of 233 manuscripts submitted to CME from 1983 to 1992 found that less than 5% made a theoretical contribution (p. 233). The extent to which this debate has been picked up in different domains of CEM largely remains unexplored. One such domain that can illuminate how the methodological debates...
in CEM are shaping its sub-fields is Offsite Manufacturing (hereafter OSM).

We single out OSM as domain of CEM because first, although not a new construction approach, OSM has recently gained renewed significant attention in both policy (e.g. IPA 2019 for the UK; DEVB 2020 for Hong Kong) and research (Goodier & Gibb 2007, Li et al. 2014, Wuni and Shen 2020) owing to its espoused benefits over traditional construction techniques. Accordingly, there has been a growing number of systematic reviews focussing on OSM (c.f Gao et al. 2020, Wuni & Shen 2020). Second, and crucially, we find that there is limited methodological debate in the burgeoning literature on OSM, making it difficult to ascertain how this body of scholarship engages with the methodological debate already started in CEM literature. Scholars who have attempted this endeavour tend to focus on research methodology as part of other research objectives, such as research themes, publication outlets, leading authors, research institutions and countries of publications (Li et al. 2014, Hosseini et al. 2018, Liu et al. 2019). This lack of studies focussed exclusively on research methodologies has, in some cases, contributed to a conflation of several components of research methodologies. This, in our view, makes it difficult to fully take stock of the methodological debates in the OSM literature. It also makes it difficult to ascertain the consistency of research methodologies with long-established relationships between components of research methodology, as explained later in this paper. Also, echoing Fellows & Liu (2015), as OSM is a fairly nascent research sub-field of CEM that draws inspiration, approaches and analytical insights from other industries, chiefly manufacturing, it is paramount that attention is given to the rigour of their research methodologies.

Against this backdrop, this study poses two questions: (i) what research methodologies are employed in the OSM literature? and (ii) how consistent are research methodologies in OSM with established relationships between different components of research methodology? Taking stock of the research methodologies in the OSM literature is crucial for two reasons. Firstly, OSM is a domain of CEM and therefore it is intellectually warranted to take stock of its methodologies in relation to the long-standing methodological debates in the wider CEM literature. This will help in judging the extent to which OSM scholars have remained with or departed from the battle for paradigm primacy in CEM literature, thereby ascertaining whether this aspect of construction is fostering a path-dependency in terms of research methodology, or whether it is pivoting towards the invitation for methodological plurality (Dainty 2008). Secondly, inquiring into the components of research methodologies will help inform the extent to which research findings reported in OSM can be relied upon by researchers seeking methodological inspiration and by policymakers looking for robust scientific evidence to inform their decision-making. Thirdly, by giving exclusive attention to the methodologies deployed in OSM research, we offer insights about the technocentric nature of studies in the area (cf. Li et al. 2014) and provide avenues for future research that will benefit from methodological plurality to move the body of knowledge towards more socio-technical, organisational and management-oriented research informed by theories from the social sciences (cf. Fellows and Liu 2020). In doing so, we offer contributions by complementing existing knowledge about OSM research, highlighting the prevailing trajectory of commonly deployed methodologies and explaining how they relate to existing methodological debates in the wider CEM literature, thereby clarifying the methodological directions of existing research.

The rest of the article is organized as follows. Section 2 introduces OSM, highlighting why it has taken centre stage in construction project delivery. It then elaborates on what research methodology entails, setting out a conceptual linkage between the components of research methodology. Section 3 briefly presents the few OSM review articles that report on research methodology to highlight some confusion identified in the use of the terminology in the literature. Section 4 explains the methodology adopted for this paper while Section 5 presents the findings. Section 6 discusses the results and Section 7 offers a conclusion.

**Literature review**

**Offsite manufacturing: What is it?**

Offsite manufacturing (OSM) refers to an innovative approach to construction involving the design and production of non-volumetric (non) structural components or volumetric units in a factory for subsequent installation in their final positions in a structure on site (Goodier and Gibb 2007). It includes the design of a significant number of building components – such as reinforced concrete walls, floors, columns, bathroom and kitchen fittings and balconies – which are then manufactured in factories to be later installed in their designated on-site location, instead of being fabricated in situ (Goodier & Gibb 2007, Wuni & Shen 2020).
This approach to construction is also referred to as offsite construction (OSC), modular integrated construction (MIC), or design for manufacture and assembly (DfMA) (Abanda et al. 2017). Although there is no universally accepted definition, and different scholars use different terminologies for the varied manufacturing-led forms of construction, regardless of nomenclature, a fundamental principle common to most definitions is to move as many conventional construction activities typically executed in situ to a regulated factory environment in a location different from the final project site (Goodier & Gibb 2007). Based on this principle, 'OSM' is used in this paper in reference to other names used in the literature.

The concept of OSM is not entirely new (Goulding et al. 2015). Some suggest it has been around as far back as 1624 when built units from the United Kingdom were sent across the Atlantic to the United States (Hosseini et al. 2018). However, the benefits and capabilities afforded by OSM, relative to the traditional approach to construction project delivery following the ongoing digital transformation in the construction industry, are certainly novel (Iuorio et al. 2019). For example, there is evidence that using OSM improves productivity and delivery time (Tang et al. 2019). It has also been shown to enhance site and workers' safety and reduce waste (Malik et al. 2019).

**Components of research methodology**

In the growing number of systematic reviews on OSM, none focuses exclusively on the research methodologies deployed. This section reviews the few that report on research methodologies as part of other research objectives. However, to show the apparent confusion regarding research methodologies reported in these studies and strengthen the case for a systematic review exclusively focussed on research methodology, we first offer an elaboration on what research methodology entails and the conceptual relationship between its different components.

Lapan et al. (2012, p. 70) explained research methodology as ‘the set of decisions and procedures that govern a study and renders it understandable to others’. It is believed that methodological considerations are rooted in ontological and epistemological debates (Zou et al. 2014, Sherratt & Leicht 2020). Ontology concerns claims regarding reality and the ‘structure of being’ (Rawnsley 1998), while epistemology relates to what we can know and how to achieve this knowledge (Hansen 2014). Although more exist, three main ontologies, namely positivism/realism, interpretivism/constructionism and pragmatism, have influenced research methodologies (Bryman 2012, Creswell 2018). Positivism holds that reality exists independent of the inquirer and hence can be systematically studied by observing and documenting the relationships between variables that make up that reality (Babbie 2012, Creswell 2018). Interpretivism rejects any claim to objective knowledge, positing that reality is a product of social construction, and that inquirers bring their subjective biases to play when constructing meaning and interpreting reality (Bryman 2012). Pragmatism acknowledges limitations with both positivist and interpretivist perspectives about reality, by contending that the best way to make sense of complex social reality is to adopt ‘what works best’ for the task at hand, including drawing on both positivist and interpretivist paradigms (Johnson & Onwuegbuzie 2004, Feilzer 2009).

According to Lapan et al. (2012, p. 71), ‘research methodology guides the choices researchers make with respect to sampling, data collection and analysis’. Methodology, therefore, comprises research design and methods, data collection instrumentation, data sources, analytical techniques, and modes of establishing reliability and validity, which themselves are also influenced by ontological and epistemological leanings (Babbie 2012, Zou et al. 2014, Creswell & Creswell 2018).

Research methods comprise qualitative, quantitative and mixed methods (Johnson & Onwuegbuzie 2004). Quantitative methods are typically rooted in positivistic ontologies and are characterized by adopting research designs that allow for an ‘objective’ analysis of the relationship between variables, by collecting numerical data and employing statistical techniques usually following some hypothesis (Dainty 2008, Agyeekum-Mensah et al. 2020). This method achieves credibility, validity and generalisability by paying attention to parameters such as sample size and sample selection, internal consistency of constructs, statistical confidence, and robust checks (Creswell & Creswell 2018). A qualitative method on the other hand is usually grounded in interpretivism and attaches importance to rich textual data, including written and spoken words, meanings associated with objects and human behaviour (Silverman 2013). It relies on data collected from research participants in their natural settings and is usually context-specific (Johnson & Onwuegbuzie 2004).

Qualitative methods often adopt an inductively grounded approach to theory building (Creswell & Creswell 2018). Because a qualitative method
prioritizes ‘thick descriptions’ and subjective meanings over statistical representativeness, it relies on expert insights, peer reviews and debriefings with research participants to establish reliability and validity (Lincoln & Guba 1986). A mixed method integrates both quantitative and qualitative methods within a single study (Johnson & Onwuegbuzie 2004). It proceeds on the basis that both quantitative and qualitative methods have their respective weaknesses which can be overcome through the integration of designs and/or data (Abowitz & Toole 2010), by mixing both methods or data within, or across, different stages of the research process, or from the outset of the research (Johnson & Onwuegbuzie 2004).

Research design describes the specific strategies adopted to select research participants, collect data and conduct analysis following research questions posed (Bell et al. 2019). Quantitatively-informed research designs include different forms of experiments and modelling that allow for the objective examination of relationships between variables of interest (Creswell & Creswell 2018). Qualitatively-informed designs include ethnography, grounded theory, phenomenology, case studies, and narrative research that allow researchers to, respectively, embed themselves in their research context to gain an in-depth understanding of social phenomena, generate theories that are data-led, understand the essence of experience, develop an in-depth insight, and explore the life of an individual (Miles & Huberman 1999, Khan 2014, Yin 2018). Mixed method designs include, among other things, different case studies that integrate both quantitative and qualitative methods (Yin 2018).

Data relates to raw material produced by abstracting the world into categories, measures and other representational forms such as numbers, characters, symbols, images, etc. (Kitchin 2014a). Data can be quantitative, qualitative, or both. Quantitative data include numerical figures measured on either a ratio or interval scale, usually collected using instruments such as self-administered or online surveys/questionnaires, bibliometric databases, among others (Bryman 2012). Qualitative data comprise texts, graphical images gathered through participant observations, different forms of interviews, workshops, and focus group discussions (Hox & Boeije 2005, Bryman 2012).

Analytical technique specifies how we move from data to understanding, explaining and interpreting phenomena of interest (Cohen et al. 2018). As the object of any research analysis is data, analytical techniques are correspondingly applied to both quantitative and qualitative data. Quantitative analytical techniques include, but are not limited to, descriptive statistics, such as measures of central tendencies and dispersion (e.g. mean, standard deviation), and inferential statistics, such as correlation, analysis of variance and regression (cf. Dainty 2008, Agyekum-Mensah et al. 2020). Analytical techniques used for qualitative data include ‘method of constant comparison, keywords-in-context, word count, classical content analysis, domain analysis, taxonomic analysis, componential analysis’ (Leech & Onwuegbuzie 2007, p. 563).

**Relationship between components of research methodology**

Within the scientific community, the components of research methodology expounded above have well-established relationships to which any scientific research usually adheres to meet the rigours of scientific knowledge production. For example, it is incongruous for research grounded in a positivistic ontology to rely on face-to-face interviews as a data source, or to rely on discourse analysis as an analytical technique. Likewise, research grounded in an interpretivist paradigm will breach established methodological conventions if it employs regression and correlation as analytical techniques. As Dainty (2008, p. 10) pointed out, ‘those who eschew the tendency to position themselves in a particular camp run the risk of finding themselves in a methodological no man’s land’. This suggests that studies that shun these established relationships between components of research methodology run the risk of the scientific community not accepting their scholarship. According to these established relationships, which all derive from researchers’ ontology, the research method chosen will firstly influence the type of research design selected for an inquiry. The type of research design chosen will in turn determine the type and sources of data drawn upon, which will thus determine the appropriate analytical techniques to be adopted. Figure 1 illustrates the relationships between the methodological components described above.

From the relationship explained above, it will follow that published scientific research will almost always adhere to these established relationships between components of research methodology. Hence, any test of association between methodological components reported in published scientific research should reveal a statistically significant association. It is therefore plausible to expect to find similar statistically significant associations between the components of research
methodology reported in the OSM literature if the studies reported are methodologically coherent. In this study, we test the relationship between the following paired components of research methodology reported in the OSM literature: (i) research method and research design, (ii) research method and data source, (iii) research method and analytical technique, and (iv) research method and data source, to ascertain whether they adhere with these established methodological relationships set out above (see Figure 1). We now review research methodologies reported in systematic reviews on OSM-related articles.

**Research methodologies reported in OSM systematic literature reviews**

In their work on environmental performance of buildings constructed using OSM, Jin et al. (2020) reviewed 43 articles and found that the research methodologies employed were lifecycle analysis (44.2%), simulation/modelling (34.9%), literature reviews (16.3%), case studies (14%), site monitoring (4.7%), descriptive storey telling (4.7%) and thermal testing (2.3%). Examining stakeholder perceptions about the quantifiable benefits and barriers of offsite construction, Senger et al. (2020) reviewed 24 articles about the benefits and barriers of OSM. They found that the main methodologies used included questionnaires (n = 19 or 79%), interviews (n = 8 or 33%), workshops (n = 6 or 25%) and case studies (n = 3 or 12.5%). Similarly, critically appraising the latest trends of research in the management of prefabrication construction (MPC), Li et al. (2014) reviewed 100 articles published in top ten CEM journals from 2000 to 2013, and documented that researchers collected their data using four ways, namely, case studies (43%), surveys (34%) literature reviews (16%) and experiments (9%). They further reported that three analytical techniques, namely, simulation/modelling (48%), statistical analysis (27%) and descriptive statistics (25%) were the most popular. In another study, Masood et al. (2017) aimed to contribute towards conceptual and theoretical development of supply chain management in housing developed using OSM. They examined 39 articles from 1996 to 2017 and suggested that the most common methods used in housing-offsite manufacturing-supply chain management were: mixed methods (38.5%), case study (35.9%), survey/interview (17.9%) and conceptual (7.7%).

It is clear that there is some confusion in the methodologies reported in these reviews. For example, Jin et al. (2020) combined analytical techniques such as lifecycle analysis with literature review, which is a data-gathering approach, and present both as methods. Similarly, Li et al. (2014) also combined a case study, which is a research design, with face-to-face interview, which is a data collection strategy, as data collection approaches. Likewise, Senger et al. (2020) combined a case study, which is a research design,
with workshops and interviews, which are data sources, and present both as methodologies. This lack of clarity provides a strong basis for interrogating the research methodologies employed in the burgeoning literature on OSM to ascertain their methodological plurality or otherwise, and the extent to which they cohere with the established relationships in the research methodology outlined. The next section presents the paper’s research methodology.

Research design and methods

To answer the research questions posed, the study adopted a systematic review as our data gathering approach. Given that different terminologies or key-words such as offsite construction, modular construction, and prefabricated construction are used interchangeably in examining manufacturing-based approaches to construction, it was useful to provide an operational definition for what we mean by offsite manufacturing (OSM). This approach provides grounds for including some key-words in our literature search and inclusion of articles.

We borrowed from Goodier and Gibb’s (2007) definition of offsite manufacturing in adopting a broad operational definition for OSM – an innovative approach for the delivery of building projects involving a significant fabrication and configuration of unit, subcomponent and volumetric elements or configurations for buildings in a location that is different to varying stages of completion prior to their final installation on a site for a built asset. In other words, a construction approach that involves replacing many conventional construction activities typically executed in situ with factory-based fabrication of building components before their subsequent assembly at a final project site. It is worth highlighting that traditional onsite construction routinely uses manufactured components/products (e.g. doors, windows, sockets, roof trusses). Such sub-components are not considered in sampling articles for analysis in this paper. Based on the operational definition, our focus on OSM in the sampled articles is about more comprehensive assemblies, including entire buildings as well as volumetric and non-volumetric elements (e.g. bathroom and kitchen pods, wall and floor panels, pre-finished external cladding) used in the construction of all forms of permanent new buildings. This operational definition reflects the manufacturing-based principle shared across the different terminologies used in other studies, as earlier noted in the literature review. Additionally, in undertaking the review, this definition allowed us to check whether the meanings of related terminologies like MiC, OSC, modular construction, and prefabricated construction were consistent with our operational definition.

Guided by our operational definition of OSM, we proceeded with the search for relevant literature. First, we conducted a preliminary Boolean search using the phrase ‘offsite manufacturing’ in academic databases such as SCOPUS, EBSCO, ASCE Library, Web of Science, and Engineering Village to see which database holds the highest number of publications. SCOPUS was the highest, returning 471 hits while ASCE Library, EBSCO, Engineering Village, and Web of Science, and returned 108, 163, 247 and 396 hits, respectively.

With SCOPUS providing the highest hits, a full search of this database was conducted on 31 January 2020. The keywords used for the search included – ‘offsite manufacturing’, ‘off-site manufacturing’, ‘offsite construction’, ‘off-site construction’, ‘industrialized building’, ‘modular construction’, ‘prefabrication’ and ‘DfMA’. These were combined with other keywords such as ‘construction’ and ‘construction project’. The scope of these words was set to the titles and abstracts of articles held in the database. It is important to mention that these keywords are by no means exhaustive, however, they are consistent with those used in systematic reviews on OSM by other scholars such as Liu et al. (2019) and Hosseini et al. (2018). No time limit was defined for the search and hence all articles with the keywords specified and published up to 31 January 2020 were retrieved. A total of 513 hits were returned. This was whittled down by using the following exclusion criteria. Firstly, 91 documents that were duplicated and bore ‘no author details’ were removed. This reduced the number of documents to 422. Secondly, 262 documents that were not published journal articles written in English were excluded, including conference articles, book chapters, books and industry/business articles. This brought the total number of articles to 160.

The abstracts of these 160 articles were reviewed to determine their suitability for final selection. The articles selected for inclusion were those that focussed on: (i) OSM or any manufacturing approach under other nomenclature (such as OSC, DfMA, MiC, etc.), or (ii) construction of a built asset such as buildings, bridges, etc. Articles that focussed on the installation of prefabricated pipelines for oil and gas, for example, were excluded. Following these criteria for inclusion, a total of 74 articles were finally selected for an in-depth review to extract the relevant data. It is important to mention that the final number of articles selected compares satisfactorily with other recently published systematic reviews in the CEM literature on
manufacturing-led construction approaches, including OSM (e.g. Masood et al. 2017 reviewed 39 articles) and MiC (e.g. Wuni & Shen 2020 reviewed 55 articles). Figure 2 summarizes the sampling steps followed.

The methodologies in the selected articles were critically reviewed and documented by asking the following questions: (1) what research methods were employed? (2) what research design was adopted for the study? (3) what data sources were drawn upon? and (4) what analytical techniques were employed? Also, considering the debates regarding the limited use of theory in the CEM literature (Sage et al. 2014, Schweber 2015), we extracted data on the use of theories or conceptual frameworks in the selected articles. It is worth mentioning that some of the articles did not report on all the components of research methodologies as outlined earlier, and such missing components were denoted as ‘unspecified’.

The data were coded into the different components of research methodologies. We employed two main analytical techniques to help answer the research questions. The inclusion of descriptive statistics (frequencies, percentages) helped to answer the first research question. To answer the second, we employed a chi-square test of independence to ascertain the ‘independence across two categorical variables’, which in this study, are the paired methodological components stated earlier (Franke et al. 2012, p. 449). We also show the effect size of the association between the categorical variables by reporting Cramer’s V which categorizes the different

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**Figure 2.** Summary of the sampling stages.
effect sizes as follows: small effect $= 0.07 – 0.21$, medium effect $= 0.21 – 0.35$, and large effect $> 0.35$, for variables with 2 degrees of freedom (Gravetter & Wallnau 2007, p. 603).¹ Both the coding, data cleaning and statistical analysis were performed using the Statistical Package for Social Scientists (SPSS) v.27.

Findings

A Brief overview of the data

Before presenting the findings related to the methodologies used in the selected studies, a brief overview of the data is warranted. The 74 articles were drawn from 23 journals, some of which are among the highly-ranked in CEM research, including Automation in Construction (16.2%), Construction Management and Economics (10.8%), Construction Innovation (5.4%), Journal of Construction Engineering and Management (4.1%), Energy and Buildings (2.7%), Journal of Architectural and Engineering (1.4) (c.f., Li et al. 2014, Hosseini et al. 2018). Appendix 1 provides a full list of the journals. The year of publication for the reviewed articles ranged from 1992 to 2020 (31 January 2020), with volatilities in the trend up to 2016, followed by a consistent increase in the number of publications, peaking at about 35% in 2019 (see Figure 3). This timeline is generally consistent with other studies, such as Ayinla et al. (2019), who investigated conceptual clarity in the use of OSM.

Contextualising the methodologies used in the reviewed articles

Before reporting the methodologies used in the reviewed articles, some context is warranted. According to Creswell (2018), the type of research question(s) posed informs the methodology finally adopted. Yin (2018) also added that case studies, for example, are best suited for studies that ask questions about ‘how’. While it is true that it is by examining the specific question(s) posed by the research that we are able to judge the suitability of the research methodologies subsequently employed, it is beyond the scope of this research to conduct this examination in this article. Instead, what we have done is to provide the research themes into which the reviewed articles can be categorized. This way, we can easily match the thematic area of each article against the research method adopted. The 74 articles reviewed were categorized into thirteen thematic areas (see Figure 4). These themes were drawn using a three-step approach. First, we took notice of common thematic areas captured in extant literature on OSM. This body of work transcended the 74 journal articles we had shortlisted to include reports, book chapters, government white papers and policy briefs. By including themes from the extant literature, we obtained a reference against which we could compare the themes from the 74 articles. We then reviewed the aims/objects, research question and contributions of the 74 articles sampled and extracted relevant thematic areas.

Figure 3. Distribution of OSM articles reviewed across different years. Source: Authors’ review data (January 2020)
(See Appendix 2). Third, we then checked the themes generated solely from the 74 journal articles against those gleaned from the extant literature and adopted those that were similar. Where the theme from our 74 articles did not fit within those from the extant literature, we adopted our generated themes. Also, while it may be true that there is no firmly established relationship between research themes and research methods, some themes tend to lean more towards some research methods than others.

For example, we found that the majority of articles (13.5%) that fall under the ‘component production’ theme disproportionately adopted quantitative methods (see Malik et al. 2019, An et al. 2020, running tests to identify optimal production matrices). The same can be found for articles that are categorized under ‘sustainability’ (4.1%) (see Hu et al. 2019) and ‘performance analysis’ (2.7%) (see Salama et al. 2017). In contrast, all articles falling under the ‘policy’ theme (5.4%) employed qualitative methods (see Goulding et al. 2015, Yang et al. 2019). Whilst not making any generalisation, it can be appreciated that, even at face value, thematic areas have some methodological leanings.

Turning attention towards the types of research methods employed in the reviewed articles alone, Figure 4 makes it evident that quantitative methods is the most used method in the OSM literature, accounting for 43% of the articles reviewed. Qualitative methods came second, also accounting for 30% of the reviewed articles, while mixed methods ranked third at 20%. Nearly 7% of the articles reviewed did not specify any research method.

While the statistics on the distribution of research methods in the OSM literature is generally in line with the long-held view that CEM research is dominated by positivistic ontologies and quantitative methods (Seymour & Rooke 1995, Dainty 2008), it is a departure from Agyekum-Mensah et al. (2020) recent finding that qualitative methods are rather popular by a share of 41.4% of all 4,166 manuscripts submitted to JCEM, ECAM, CME and ARCOM between 2000 to 2017 as against 33.1% and 16% for quantitative and mixed methods respectively. The difference, however, between our finding and that of Agyekum-Mensah et al. (2020) could be because our study focuses exclusively on OSM literature, a particular aspect of the CEM literature, while the latter encompasses a much wider scope. Another reason could be attributed to the differences in the total number of articles and the number of journals from which the reviewed articles are sampled. We elaborate the implications of this distribution of research methods in our discussion section.

Use of theories and conceptual frameworks in the OSM literature

According to Campbell (1990, p. 65) ‘a theory identifies what variables are important for what reasons,
specifies how they are related and why, and identifies conditions under which they should be related or not. Fellows & Liu (2020) added that a theory offers ‘methodological advice and guidance’ and hence remain ‘essential for the adoption of appropriate methods of data collection, resultant data sets and analyses’ (p. 584). The long-held view among some CEM scholars (Betts & Lansley 1993, Schweber 2015, Chan 2020) is that there is very limited use of theory in the field. Our study confirmed this claim. It revealed that, of the 74 articles reviewed, only 14.9% used a theory or a theoretical framework (see Table 1). Some examples of theories used and the articles in which they were applied include the ‘theory of modularity’ used in Bekdik et al. (2018), to investigate the design process of façade elements used in the construction of offsite manufactured buildings, and ‘production strategy theory’ in Jonsson and Rudberg (2017), to develop a matrix for classifying production systems for construction with various degrees of industrialisation.

The limited use of theory seems, however, to have been compensated for by an appreciable use of conceptual frameworks or models, with 66.2% of the articles grounding their analysis in some conceptual frameworks. Examples of frameworks used include ‘modularisation as a continuum’ in da Rocha & Kemmer (2018) to investigate the concept of modularity in construction and its application for building projects, and ‘a digital quality assessment framework’ used in Kim et al. (2016) to develop a non-contact design for quality (DQA) technique that automatically and precisely assesses the key quality checklists of a full-scale precast concrete element with complex geometry.

Analysing the use of both theory and conceptual frameworks across the different research methods revealed that articles that employed mixed methods used theories the most (45.5%), while those that employed quantitative methods employed conceptual frameworks the most (50%) (See Figure 6). It is clear from Figure 6 that qualitative methods trails both quantitative and mixed methods in terms of the use of both theory and conceptual framework. We elaborate on the implications of this finding in our discussion.

Furthermore, the preference for quantitative methods over other methods in the articles reviewed can still be observed when the data is viewed across time. As Figure 7 shows, in years when both quantitative and qualitative methods were represented, the quantitative studies remained the most used method (see the years 2014, 2015, 2016, 2017, 2019). However, it is
also worth pointing out that there were years when only articles that used qualitative methods were represented (see the years 1992, 2003, 2007 and 2013), as well as years when qualitative articles exceeded both quantitative and mixed methods in the same year (see the years 2010, 2012, 2018).

Also, it is worth mentioning that articles that employed mixed methods exceeded those that used qualitative studies in 2019. This however is not a repeated pattern in the sampled articles. Thus, overall, although the quantitative method remains the most used research method in the OSM literature, there is some degree of plurality.

Research designs employed in the OSM literature

The research designs identified comprised both stand-alone and hybrid research designs. Case studies were the most common stand-alone research design, constituting about 38%, when both single case study (27%) and multiple case studies (11%) are combined (See Figure 8). This was followed by systematic reviews (17.6%), experimental modelling (12.2%) and scoping reviews² (4%). ‘Case study with modelling’ ranked first in hybrid design (13.5%), followed by ‘systematic review and case study’ (2.7%). Notably, 12% of the sampled articles do not specify any kind of research design.
Overall, the findings, especially the stand-alone designs, are consistent with Li et al. (2014) who also found that case studies were the most common research methodology, accounting for some 43% of articles reviewed in their study. The growing prominence of systematic reviews is also worth noting as previous CEM research (e.g. Taylor & Jaselskis 2010) found that systematic reviews made up only 1% of the 1,102 manuscripts published in JCEM. Equally noteworthy is the increasing adoption of modelling, also identified by Taylor & Jaselskis (2010) in their systematic review. Overall, as with research methods, there appears to be some plurality in research designs in the emerging scholarship on OSM.

**Data sources used in OSM literature**

The study found that a total of 17 data sources were drawn upon in the selected articles (excluding studies with ‘unspecified’ sources). These data sources comprised 7 stand-alone sources and 10 hybrid sources. Of the stand-alone data sources, the top five included bibliometric databases (21.6%), project information (12.2%), surveys (8.1%), factory data (5.4%) and expert interviews (2.7%) (See Figure 9). For the 10 hybrid data sources, six articles combined two data sources and two drew on more than two sources. Among the hybrid data sources, the top three included ‘site visit and others’ (12.2%), ‘expert interview, site visit and others’ (9.5%), ‘bibliometric database and expert interviews’ (2.7%), ‘survey and expert interviews’ (2.7%), ‘expert interview and workshop’ (2.7%). It is instructive to point out that although ‘expert interview’ ranks fifth as a standalone data source, at 40% it is the most popular source used in hybrid data sources.

It is also worth noting here that in the study by Li et al. (2014), it was found that, respectively, case studies, surveys, literature reviews, and experiments accounted for 43%, 32%, 16% and 9% of the sources of data drawn upon in the studies they reviewed. This higher proportion may be attributed to the fact such studies do not disaggregate the data sources into stand-alone and hybrid as we do in this paper. Also, what is clear from the OSM literature is the significant use of data sources that fall within the mixed methods. The use of ‘bibliometric database, workshop, site visits and focus groups’ in the articles reviewed is a clear example of this.

**Analytical techniques used in the OSM literature**

Regarding the types of analytical techniques employed, a total of 18 were identified, excluding those ‘unspecified’ (see Figure 10). Of these, 13 articles representing 72% were stand-alone techniques while the remaining five, representing 28% were hybrid analytical techniques. Of the stand-alone techniques, nine articles, representing 69.2% are quantitative while the remaining four were qualitative. The three most used stand-alone techniques identified were modelling (16.2%), content analysis (8.1%) and the analytical hierarchical process (6.8%). Of the four hybrid analytical
techniques, the three notable ones included ‘descriptive and process analysis’ (11.1%), ‘descriptive statistics and ranking’ (8.1%) and ‘descriptive statistics and content analysis’ (2.7%). It is clear from this that analytical techniques that are consistent with quantitative methods remain popular in the OSM literature, despite an appreciable use of qualitative and mixed method-oriented analytical techniques.
Our findings are in agreement with those of Li et al. (2014), who found that simulation or modelling, statistical analysis and descriptive statistics accounted for 48%, 27% and 25% of the analytical techniques employed in their OSM literature review, respectively.

**Analysing the relationships between key components of methodologies in the OSM literature**

The null hypothesis running through the test is that there is an equal distribution between any paired components of research methodology and thus any test of association should result in no statistically significant association. However, for the components of research methodologies reported in the OSM literature to cohere with the established relationships between the components of research methodology outlined earlier, we would expect to find a statistically significant association between the paired relationships. Anything short of this would be interpreted as incoherence in the methodological components reported in the sampled OSM literature.

**Relationship between research methods and research designs employed in the OSM literature**

The cross-tabulation in Table 2 reveals that the majority of studies that use single case study designs also use either quantitative (34.4%) or qualitative methods (27.3%), while those designed as multiple case studies often use mixed methods (26.7%). Also, there is an uneven distribution in the proportion of each research design per research method. For example, of studies designed to use experimental modelling, 25% of sampled articles apply quantitative methods, 6.7% mixed methods and 0% qualitative methods. Similarly, while 13.6% of scoping reviews employ mixed methods, no quantitative nor mixed methods are employed for such a design. Perhaps surprisingly, systematic reviews are under-represented in quantitative methods (9.4%) relative to both qualitative (22.7%) and mixed methods (20%).

This suggests that some research methods are used more frequently for some research designs than others. The chi-square test of independence between research methods and research design reveals a statistically significant association between the two components, \((\chi^2) = 34.001, \text{df} = 21, p\text{-value} = 0.036**, Cramer’s V = 0.391 ** < 95% Confidence Interval.

**Relationship between research methods and analytical techniques employed in the OSM literature**

The uneven distribution of analytical techniques across different research methods is stark (see Table 3). While 34% of quantitative studies employ modelling, no qualitative or mixed method-oriented studies use this analytical technique. Similarly, single case descriptive analysis is disproportionately used in studies employing qualitative methods (18.2%) in comparison to studies that use quantitative (3.1%) and mixed methods (0%). Likewise, ‘descriptive statistics and ranking’ (20%) is disproportionately used in studies employing mixed methods when compared to those employing quantitative (6.3%) and qualitative methods (13.6%). This suggests a bias in analytical techniques across different research methods.

Given this uneven distribution, it is unsurprising that a chi-square test of independence confirmed a statistically significant association between the research methods and the analytical techniques, \((\chi^2) = 49.008, p = 0.001, \text{with large effect size (Cramer's V} = 0.470). This suggests that the selected
OSM studies adhere to the established methodological relationship between research methods and analytical techniques adopted in a study.

**Relationship between data sources and analytical techniques employed in the OSM literature**

Table 4 illustrates the uneven distribution regarding the relationship between data sources and analytical techniques. Studies that use only ‘surveys’ adopt factor analysis or structural equation modelling (33%); similarly, ANOVA is solely used in studies that draw on project information (11%). Analytical Hierarchical Process (AHP) is more popular with studies that draw on surveys and expert interviews (50%) than with those using only surveys (16.7%) and ‘site visit and others’ (11.1%). A chi-square test of independence revealed a statistically significant association between the type of ‘data sources’ and ‘analytical techniques’ used, \( (\chi^2) = 306, n = 74 \), with a large effect size \( (Cramer’s V = 0.560) \). Again, the null hypothesis is rejected in favour of the alternative hypothesis that specific data sources lend themselves to specific analytical techniques, and the OSM literature has kept with this established methodological relationship.

**Relationship between research methods and data sources employed in OSM literature**

Table 5 shows that some data sources are used for specific research methods. For example, we find that only quantitative methods used surveys (100%). The same observation applies to qualitative and mixed methods and the use of ‘focus group discussion’ (100%) and ‘project information + interviews’ (100%) respectively. Notwithstanding this observation, some analytical techniques do not appear to be uniquely associated with specific research methods. For example, 50%, 25% and 12.5% of studies that use qualitative, quantitative and mixed methods respectively employ bibliometric database; likewise, 55.5%, 33.3% and 11.1% of studies that use quantitative, qualitative and mixed methods respectively employ ‘site visits + others’. Accordingly, our chi-square test of independence reveals no statistically significant association between research methods and the type of data sources drawn upon, \( (\chi^2) = 51, n = 74 \), with a large effect size \( (Cramer’s V = 0.530) \). Thus, the null hypothesis that there is no statistically significant association between research methods and data sources is validated.

It is therefore concluded that the literature on OSM does not adhere to any established relationship between research methods and data source. This is a surprising finding given that received wisdom suggests that these two components are strongly associated. This may be interpreted to mean that some scholars researching OSM are either becoming methodologically indiscipline or are pushing the remit of methodological debates a step further.

**Discussion**

The findings revealed in this review paper bring forward several issues that merit discussion within the
## Table 4. Crosstabulation between types of data and analytical techniques employed in OSM literature.

<table>
<thead>
<tr>
<th>Analytical techniques</th>
<th>Bibliometric Database</th>
<th>Bibliometric Database + Expert Interviews</th>
<th>Project Information</th>
<th>Expert Interviews + Site Visits + Others</th>
<th>Surveys</th>
<th>Survey + Expert Interview</th>
<th>Site Visit + Others</th>
<th>Unspecified</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analytical Hierarchical Process (AHP)</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (16.7%)</td>
<td>1 (50%)</td>
<td>1 (11.1%)</td>
<td>0 (0.0%)</td>
<td>16 (100%)</td>
</tr>
<tr>
<td><strong>Comparative descriptive analysis</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>2 (22.2%)</td>
<td>2 (28.6%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>2 (12.5%)</td>
</tr>
<tr>
<td><strong>Computational hypothesis testing</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (14.3%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (16.7%)</td>
</tr>
<tr>
<td><strong>Content analysis</strong></td>
<td>2 (12.5%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (14.3%)</td>
<td>1 (16.7%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>2 (22.2%)</td>
</tr>
<tr>
<td><strong>Single case descriptive analysis</strong></td>
<td>2 (12.5%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (14.3%)</td>
<td>1 (16.7%)</td>
<td>0 (0.0%)</td>
<td>1 (11.1%)</td>
<td>0 (0.0%)</td>
<td>3 (27.3%)</td>
</tr>
<tr>
<td><strong>Descriptive statistics and ranking</strong></td>
<td>3 (18.8%)</td>
<td>1 (50%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (11.1%)</td>
<td>0 (0.0%)</td>
<td>5 (6.8%)</td>
</tr>
<tr>
<td><strong>Descriptive statistics and trend analysis</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>2 (12.5%)</td>
</tr>
<tr>
<td><strong>Descriptive and process analysis</strong></td>
<td>1 (6.3%)</td>
<td>0 (0.0%)</td>
<td>2 (22.2%)</td>
<td>1 (14.3%)</td>
<td>0 (0.0%)</td>
<td>1 (50%)</td>
<td>1 (11.1%)</td>
<td>0 (0.0%)</td>
<td>2 (22.2%)</td>
</tr>
<tr>
<td><strong>Multi-Criteria Analysis</strong></td>
<td>0 (0.0%)</td>
<td>1 (50%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (12.5%)</td>
<td>3 (27.3%)</td>
</tr>
<tr>
<td><strong>Modelling</strong></td>
<td>2 (12.5%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>3 (33.3%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (12.5%)</td>
<td>0 (0.0%)</td>
<td>1 (6.3%)</td>
</tr>
<tr>
<td><strong>Unspecified</strong></td>
<td>5 (31.3%)</td>
<td>0 (0.0%)</td>
<td>1 (14.3%)</td>
<td>1 (16.7%)</td>
<td>0 (0.0%)</td>
<td>3 (33.3%)</td>
<td>0 (0.0%)</td>
<td>3 (27.3%)</td>
<td>16 (100%)</td>
</tr>
<tr>
<td><strong>Cluster analysis</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>2 (12.5%)</td>
</tr>
<tr>
<td><strong>Content and discourse analysis</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>2 (12.5%)</td>
</tr>
<tr>
<td><strong>GIS Spatial Analysis</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>5 (6.8%)</td>
</tr>
<tr>
<td><strong>Factor Analysis/Structural Equation Modelling</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>2 (33.3%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>7 (8.1%)</td>
</tr>
<tr>
<td><strong>ANOVA</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (11.1%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>5 (6.8%)</td>
</tr>
<tr>
<td><strong>Life-Cycle Analysis</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (16.7%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>5 (6.8%)</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>12 (16%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>16 (100%)</td>
<td>2 (100%)</td>
<td>9 (100%)</td>
<td>7 (100%)</td>
<td>6 (100%)</td>
<td>2 (100%)</td>
<td>9 (100%)</td>
<td>8 (100%)</td>
<td>74 (100%)</td>
</tr>
</tbody>
</table>

**Pearson Chi-square ($\chi^2$) = 402.63, df = 306, p-value = 0.001**. Cramer's $V = 0.565$. Note ** denote 95% Confidence Interval.
This study appears to re-echo the views of scholars who have expressed concerns about the dominance of positivistic ontologies in CEM research (Seymour & Rooke, 1995, Dainty, 2008, Sage et al., 2014), that it reduces construction and project delivery—a complex endeavour comprising multi-faceted organisational, technological, institutional and human factors—into isolatable and measurable components or constructs. (In)advertently, the dominance of quantitative methods appears to have been carried over to the burgeoning scholarship on OSM, a development that is likely to further entrench the positivistic ontology and methodologies following OSM scholars’ penchant for quantifying or measuring, in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shahzad et al., 2015 for the quantification of such benefits; Bertram et al., 2019). If the prevalence of positivistic ontologies and quantitative methods—as the most used paradigm and method respectively—goes unquestioned, it could create the impression that this sub-field of CEM scholarship has an implicit bias for quantitative methodologies following OSM scholars’ penchant for quantifying or measuring in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shalzad et al., 2015).

It is therefore our contention that, if the existing research on OSM fails to embrace new ways of asking questions and conducting scientific inquiries, this narrow conception of complex realities associated with construction project management (Bresnen, 2013) could create the impression that the existing sub-field of CEM scholarship has an implicit bias for quantitative methodologies following OSM scholars’ penchant for quantifying or measuring in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shalzad et al., 2015). This study appears to re-echo the views of scholars who have expressed concerns about the dominance of positivistic ontologies in CEM research (Seymour & Rooke, 1995, Dainty, 2008, Sage et al., 2014), that it reduces construction and project delivery—a complex endeavour comprising multi-faceted organisational, technological, institutional and human factors—into isolatable and measurable components or constructs. (In)advertently, the dominance of quantitative methods appears to have been carried over to the burgeoning scholarship on OSM, a development that is likely to further entrench the positivistic ontology and methodologies following OSM scholars’ penchant for quantifying or measuring, in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shahzad et al., 2015). If the prevalence of positivistic ontologies and quantitative methods—as the most used paradigm and method respectively—goes unquestioned, it could create the impression that this sub-field of CEM scholarship has an implicit bias for quantitative methodologies following OSM scholars’ penchant for quantifying or measuring in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shalzad et al., 2015). This study appears to re-echo the views of scholars who have expressed concerns about the dominance of positivistic ontologies in CEM research (Seymour & Rooke, 1995, Dainty, 2008, Sage et al., 2014), that it reduces construction and project delivery—a complex endeavour comprising multi-faceted organisational, technological, institutional and human factors—into isolatable and measurable components or constructs. (In)advertently, the dominance of quantitative methods appears to have been carried over to the burgeoning scholarship on OSM, a development that is likely to further entrench the positivistic ontology and methodologies following OSM scholars’ penchant for quantifying or measuring, in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shahzad et al., 2015).

It is therefore our contention that, if the existing research on OSM fails to embrace new ways of asking questions and conducting scientific inquiries, this narrow conception of complex realities associated with construction project management (Bresnen, 2013) could create the impression that the existing sub-field of CEM scholarship has an implicit bias for quantitative methodologies following OSM scholars’ penchant for quantifying or measuring in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shalzad et al., 2015). This study appears to re-echo the views of scholars who have expressed concerns about the dominance of positivistic ontologies in CEM research (Seymour & Rooke, 1995, Dainty, 2008, Sage et al., 2014), that it reduces construction and project delivery—a complex endeavour comprising multi-faceted organisational, technological, institutional and human factors—into isolatable and measurable components or constructs. (In)advertently, the dominance of quantitative methods appears to have been carried over to the burgeoning scholarship on OSM, a development that is likely to further entrench the positivistic ontology and methodologies following OSM scholars’ penchant for quantifying or measuring, in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shahzad et al., 2015). This study appears to re-echo the views of scholars who have expressed concerns about the dominance of positivistic ontologies in CEM research (Seymour & Rooke, 1995, Dainty, 2008, Sage et al., 2014), that it reduces construction and project delivery—a complex endeavour comprising multi-faceted organisational, technological, institutional and human factors—into isolatable and measurable components or constructs. (In)advertently, the dominance of quantitative methods appears to have been carried over to the burgeoning scholarship on OSM, a development that is likely to further entrench the positivistic ontology and methodologies following OSM scholars’ penchant for quantifying or measuring, in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shahzad et al., 2015). This study appears to re-echo the views of scholars who have expressed concerns about the dominance of positivistic ontologies in CEM research (Seymour & Rooke, 1995, Dainty, 2008, Sage et al., 2014), that it reduces construction and project delivery—a complex endeavour comprising multi-faceted organisational, technological, institutional and human factors—into isolatable and measurable components or constructs. (In)advertently, the dominance of quantitative methods appears to have been carried over to the burgeoning scholarship on OSM, a development that is likely to further entrench the positivistic ontology and methodologies following OSM scholars’ penchant for quantifying or measuring, in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shahzad et al., 2015). This study appears to re-echo the views of scholars who have expressed concerns about the dominance of positivistic ontologies in CEM research (Seymour & Rooke, 1995, Dainty, 2008, Sage et al., 2014), that it reduces construction and project delivery—a complex endeavour comprising multi-faceted organisational, technological, institutional and human factors—into isolatable and measurable components or constructs. (In)advertently, the dominance of quantitative methods appears to have been carried over to the burgeoning scholarship on OSM, a development that is likely to further entrench the positivistic ontology and methodologies following OSM scholars’ penchant for quantifying or measuring, in precise figures, the benefits that OSM has over the traditional approach to construction project delivery (see Shahzad et al., 2015).

### Table 5. Crosstabulation between the type of research methods and the types of data sources employed in the OSM literature.

<table>
<thead>
<tr>
<th>Research methods</th>
<th>Bibliometric Database</th>
<th>Expert Interviews</th>
<th>Project Information</th>
<th>Visits + Others</th>
<th>Surveys</th>
<th>Site Visit + Others</th>
<th>Unspecified</th>
<th>Expert Interview + Workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantitative Methods</td>
<td>4 (25%)</td>
<td>0 (0.0%)</td>
<td>6 (66.7%)</td>
<td>1 (14.3%)</td>
<td>6 (100%)</td>
<td>1 (50%)</td>
<td>5 (55.5%)</td>
<td>3 (37.5%)</td>
</tr>
<tr>
<td>Qualitative Methods</td>
<td>8 (50.0%)</td>
<td>0 (0.0%)</td>
<td>2 (22.2%)</td>
<td>3 (42.9%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>3 (33.3%)</td>
<td>2 (29.5%)</td>
</tr>
<tr>
<td>Mixed Methods</td>
<td>2 (12.5%)</td>
<td>2 (100%)</td>
<td>1 (11.1%)</td>
<td>3 (42.9%)</td>
<td>0 (0.0%)</td>
<td>1 (50%)</td>
<td>1 (11.1%)</td>
<td>2 (29.5%)</td>
</tr>
<tr>
<td>Unspecified</td>
<td>2 (12.5%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (12.5%)</td>
</tr>
<tr>
<td>Total</td>
<td>16 (100%)</td>
<td>0 (0.0%)</td>
<td>9 (100%)</td>
<td>7 (100%)</td>
<td>6 (100%)</td>
<td>2 (100%)</td>
<td>9 (100%)</td>
<td>0 (0.0%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research methods</th>
<th>Virtual Reality</th>
<th>Expert Interview</th>
<th>Project Information + Interviews</th>
<th>Focus Group Discussion</th>
<th>Website</th>
<th>BD + W + SV + FGD</th>
<th>Factory Data</th>
<th>Experiment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantitative Methods</td>
<td>0 (0.0%)</td>
<td>1 (100%)</td>
<td>2 (100%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>3 (75%)</td>
<td>0 (0.0%)</td>
<td>32 (43.2%)</td>
</tr>
<tr>
<td>Qualitative Methods</td>
<td>1 (100%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (100%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>22 (29.7%)</td>
</tr>
<tr>
<td>Mixed Methods</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (100%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (100%)</td>
<td>15 (20.3%)</td>
</tr>
<tr>
<td>Unspecified</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (100%)</td>
<td>1 (25%)</td>
<td>0 (0.0%)</td>
<td>5 (6.8%)</td>
</tr>
<tr>
<td>Total</td>
<td>1 (100%)</td>
<td>1 (100%)</td>
<td>2 (100%)</td>
<td>1 (100%)</td>
<td>1 (100%)</td>
<td>1 (100%)</td>
<td>4 (100%)</td>
<td>1 (100%)</td>
<td>74 (100%)</td>
</tr>
</tbody>
</table>

Pearson Chi-square ($\chi^2$) = 62.267, df = 51, p-value = 0.134, Cramer’s V = 0.530.
scholars with a penchant for quantitative methods should be mindful that using quantitative data and analytical techniques does not absolve a study of researcher biases and this should be acknowledged (Sherratt & Leicht 2020). This is because it is possible for inexperienced researchers to mistakenly rationalize that grounding their research within this popular methodological position, no matter how limiting it may be for the research, will guarantee their work acceptance in notable CEM journals. This, if unchecked, will further skew future knowledge in this section of CEM research towards quantitative methodologies, thereby setting in motion a vicious cycle.

Relatedly, it would come as no surprise that there is limited use of theory in OSM literature as this has been a common trait in the CEM literature generally (Betts & Lansley 1993, Schweber 2015, Chan 2020). However, what remains instructive is the under-utilisation of theories in OSM articles that employ qualitative methods relative to those using both quantitative and mixed methods. As our results have shown, studies that employed quantitative methods tended to use theories as frameworks to analyse empirical data (c.f. Jonsson and Rudberg 2017), rather than build upon or extend existing ones. Indeed, some scholars (e.g. Azhar et al. 2010) have claimed that CEM research is more oriented towards applied research that aims to solve real-life problems and not to discover ‘overriding theories’ as is done in the fields of pure engineering and natural science (p. 87). We contend however that limiting the use of theory in CEM research to a framework for organizing and analysing data, without emphasising the need to challenge existing theories or uncover new ones, risks foreclosing research that is exploratory and not intended to have immediately obvious, actionable impacts. Based on this study, we will rather call for more exploratory and theory-provoking research in OSM research, if this subfield is to witness the theoretical richness that transcends the action-oriented conception of CEM research. To do so will require a revisit of the philosophical debates regarding the intellectual foundations of not just OSM but construction project delivery in general and the subject matter of their inquiries (Dainty 2008). Construction management researchers need to be decisive about whether it is ‘people’ and their interactions with organisational structures, processes or simply projects that constitute the ‘object of their study’ and ‘units of analysis’, (Runeson 1997, Bresnen 2013).

Also, it is worth taking note of the gradual evolution in the use of different research methods over the years. While it remains true that studies that employ quantitative methods still remain the majority the OSM literature, it is welcoming to see that there were years when qualitative method was the only method used in the reviewed articles or it exceeded the number of articles that used both quantitative and mixed methods, as this is indicative of the fact that there is opportunity for other methods to gain prominence, if pursued further. This also means that any attempt by editors of CEM journals or CEM scholars to call for special issues on OSM topics that embrace methodological diversity, as was done by Taylor & Jaselskis (2010) in JCEM, is likely to be met with appreciable enthusiasm and hence should be encouraged.

It is also worth mentioning that some findings from this study are both promising and worrying for improving our understanding of research methodologies, particularly in the study of OSM.

The first promising finding is the significant use of conceptual frameworks in the OSM literature. A conceptual framework, according to Jabareen (2009) is not merely a collection of concepts, but rather, a construct in which each concept plays an integral role, provides an interpretative approach to social reality, provides understanding rather than theoretical explanation, is indeterminist and is based on the concept of freedom’ (p. 51). This therefore suggests that it is possible to rescue OSM from the hegemony of positivism to allow for a wider embrace of ontological and methodological pluralities to explore questions hitherto unexamined.

Secondly, recent evidence by Agyekum-Mensah et al. (2020) has shown that the dominance of qualitative methods in CEM research, and our findings regarding the growing hybridisation in different research components in the OSM literature point to the fact that methodological diversity and shift are already happening, and it is only a matter of time before we see the pendulum being swung in favour of such pluralities. For the authors, this growing hybridisation may also be interpreted as a response to the longstanding debate as to whether CEM research should be viewed as belonging to either the physical or social science or to both (Taylor & Jaselskis 2010, Sage et al. 2014). It is becoming clear that many scholars are realising the benefits to be gained by integrating research designs, data sources and analytical techniques from both quantitative and qualitative methods as Schweber (2015) pointed out.

Furthermore, it is reassuring that the burgeoning literature on OSM has largely retained some of the rudiments of scientific rigour in their inquiries by ensuring that components of methodologies reported in the sampled study cohere with the established
relationship between components of the research methodology. In light of this finding, credit should be given to editors of CEM journals and numerous anonymous reviewers for their collective diligence in ensuring that research articles published in CEM journals hold up to scrutiny when subjected to the rigours of scientific enquiries.

What we find worrying, however, is the significant number of articles in which the authors do not specify vital components of their research methodology. Recently, Sherratt & Leicht (2020, p. 7) cautioned CEM researchers about the ‘need to be explicit in our work and avoid obfuscation behind meaningless labels, such as ‘qualitative research’. Although some scholars (e.g. Dainty 2008, Agyekum-Mensah et al. 2020) have pointed out that it is common practice in CEM research for some aspects of research methodology to go unreported in published articles, we would argue that the persistence of this practice risks undermining the replicability and trustworthiness of findings reported in OSM studies and into the wider CEM literature. This is concerning given that evidence from CEM research feeds into further research, industry policies and practices (Fellows & Liu 2015). Against this backdrop, it might be helpful for editors and peer-reviewers to pay critical attention to this aspect of manuscripts submitted for publication. We are not advocating for a cast-in-stone methodological template that all manuscripts must follow to the letter, rather for the importance of placing emphasis on this issue to be included in the ‘guidelines for authors’.

So, what do the findings uncovered in this study mean for the ongoing research on OSM, the use of research methodologies in the literature, and how research evidence is or could shape policy and practice? This study has sought to bring to the fore the importance of periodic stocktaking of research methodologies employed not just in the burgeoning literature on OSM but also in CEM research generally, as previous studies (Betts & Lansley 1993, Dainty 2008, Taylor & Jaselskis 2010, Agyekum-Mensah et al. 2020, Sherratt & Leicht 2020) have demonstrated. Indeed, it is through such periodic stocktaking that as academics we can take a step back from our work and objectively assess how our field has evolved over time and responded to the new realities we face. Notably, as the use of digital technologies has become an increasingly integral part of the construction industry, causing several traditional tasks to give way to automated processes that generate substantial amounts of near real-time quantitative big data on different aspect of construction project delivery, we should be minded not to uncritically allow the axioms of positivistic ontologies and methodologies to become the leitmotif of CEM research. While figures matter, they are in themselves less meaningful except when they are contextually situated. It has become evident that construction professionals and policy makers alike require qualitative insights into the contextual underpinning of issues that are of interest in CEM research as much as they are in the insights that quantitative evidence can bring to bear (Bresnen 2013). Hence, methodological plurality should be fiercely encouraged.

Conclusion

This study was inspired by the lack of a systematic review focussing exclusively on research methodology in the growing body of literature on OSM. Concomitantly, it also addresses the seeming confusion around the use of the term ‘methodologies’ in the few available systematic reviews that report on research methodology as part of other research objectives. The study therefore sought to find out what the components of research methodology reported in the OSM literature are and how consistent are those components when compared against the established relationships between components of research methodologies in the CEM and broader research methodology literature.

Regarding the first question, the study found that, similarly to the wider CEM literature, the quantitative method remains the popular research method (43%), followed by qualitative (30%) and mixed methods (20%). Consistent with other studies (e.g. Li et al. 2014), case studies emerged as the most common standalone research design (38%), followed by systematic reviews (17.6%) and experimental modelling. For hybrid research designs, a case study combined with modelling and systematic reviews appears to be the commonly used research designs. Bibliometric database also emerged as the most prominent standalone data source (21.6%) while ‘site visits and others’ remained the popular hybrid data source (12.2%). In terms of analytical techniques, modelling was the most preferred standalone analytical technique (16.2%) while ‘descriptive and process analysis’ remained the popular hybrid analytical techniques.

Regarding the relationship between the components of research methodology in the sampled literature, the study found statistically significant associations between research design and method, research method and analytical technique, and data source and analytical technique. These findings
indicate that the literature on OSM has largely kept with the established relationships between components of research methodology, except for the relationship between research method and data source. Indeed, one would have expected to see a statistically significant association between research method and data source, as it is most likely that purely qualitative studies draw on interviews, focus group discussions or participant observations as data sources. However, it is increasingly becoming common to find data sources such as bibliometric databases being used in studies that adopt both quantitative and qualitative methods – for instance, in the case of using scientometrics to understand the relative proportions and trend dynamics of OSM topics (see Hosseini et al. 2018), and to qualitatively explore the breadth and scope of issues discussed in the OSM literature without emphasis on frequencies or trend analysis (see Jin et al. 2020). These findings highlight the need for attention to be paid to what scholars do with data gathered using a particular data source and less to whether a data source aligns with a particular research method. We are increasingly seeing large qualitative data being analysed quantitatively with the help of software applications such as cite space (see Hosseini et al. 2018).

Taken together, the findings regarding methodologies employed in the OSM literature provoke questions as to what should be used to judge whether a field is quantitative or qualitative. Should we, for example, focus on the phenomena being studied or the data that are drawn upon to make such a judgement? For OSM researchers in particular, it is critical to ask what ontological and methodological changes occur as processes within construction increasingly mimic the manufacturing sector – which has more inflexible processes in the making of predefined components. These are crucial questions that scholars studying OSM must engage with to avoid the dangers of calling in to question forms of knowledge and research methodologies that do not align with a dominant paradigm (Dainty 2008). Such reflexivity would also help construction scholars to judge how scholars thinking about these critical ontological issues has evolved with contemporary developments in the field.

It is also important to stress that, despite the contribution this paper makes towards the growing body of literature on OSM and by extension the methodological debates in CEM literature more generally, it is not immune from limitations and we acknowledge them as follows. First, although the study provides some context for the methodologies used in the articles reviewed by showing the broader themes that articles reviewed fell under, we concede that themes themselves are not substitutes for research questions, and that it is possible to find different research questions in one study, making it difficult to place such studies under a single theme. As our study does not aim to explicitly examine the appropriateness of the research methodologies employed in OSM literature for the specific questions posed, further studies that examine such relationships should be welcomed in order to deepen our understanding of methodological soundness in the OSM literature. Furthermore, although the keywords used in our search for relevant articles were generally consistent with those used in the field and in other previous systematic reviews (Hosseini et al. 2018, Liu et al. 2019), they do not constitute an exhaustive list. This means that it is possible that we have left out some existing literature that could have further informed the insights presented in this paper. Secondly, focussing solely on peer-reviewed journal articles published in English limits the scope of our sample and the results might have been different if publications in other languages were considered. Focussing on articles in English was necessary to avoid losing any meaning ‘in translation’ and appropriate given that English is the medium of communication in the majority of journals from which the articles were sampled. This limitation is one that could be tackled in the future by an international multilingual team of researchers seeking to review all existing literature in the area in different languages. Furthermore, the exclusion of conference publications, books, book chapters and industry reports could have influenced the findings. Also, in instances where sampled articles were ambiguous in terms of the elements of methodology being examined, like Dainty (2008) reasoned, judgement was applied by authors based on the articles’ contents and the nature of the results presented.

We conclude by emphasising that the methodological debates in both the general CEM literature and the burgeoning OSM literature are far from over and hence more methodologically-focussed articles would prove useful. Accordingly, future research could explore the changing relationship between research methods and data sources, and what this means for how construction project delivery using OSM is perceived from both ontological and methodological standpoints. Whether OSM should be treated as a physical or social science, and/or how it could be understood as a junction between these two sciences would be welcome areas for future research.
Notes

1. We have benchmarked the Cramer’s V co-efficient for effect sizes against two degrees because lower ranges of co-efficient are required to establish the strength of association for degrees of freedom higher than two (See Gravetter and Wallnau, 2007, p. 603).
2. The difference between a scoping review and a systematic review is that often the former does not follow a systematic process in, for example, the choice of key words, the type of documents included or excluded, or in specifying a time cut-off for the studies to be included.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research has received support from the Centre for Digital Built Britain’s (CDBB) at the University of Cambridge which is within the Construction Innovation Hub and is funded by UK Research and Innovation through the Industrial Strategy Fund.

ORCID

Richmond Juvenile Ehwi http://orcid.org/0000-0002-4679-1472
Kwadwo Oti-Sarpong http://orcid.org/0000-0002-3756-9212
Reyhaneh Shojaei http://orcid.org/0000-0003-1897-8245
Gemma Burgess http://orcid.org/0000-0002-3856-9572

References


**Appendix 1. List of journals publishing the sampled articles**

<table>
<thead>
<tr>
<th># of Journal</th>
<th>Journal Name</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Automation in Construction</td>
<td>12</td>
<td>16.2</td>
</tr>
<tr>
<td>2</td>
<td>Construction Management and Economics</td>
<td>8</td>
<td>10.8</td>
</tr>
<tr>
<td>3</td>
<td>Architectural Engineering and Design Management</td>
<td>4</td>
<td>5.4</td>
</tr>
<tr>
<td>4</td>
<td>Construction Innovation</td>
<td>4</td>
<td>5.4</td>
</tr>
<tr>
<td>5</td>
<td>Journal of Cleaner Production</td>
<td>4</td>
<td>5.4</td>
</tr>
<tr>
<td>6</td>
<td>Journal of Management in Engineering</td>
<td>4</td>
<td>5.4</td>
</tr>
<tr>
<td>7</td>
<td>Building Research and Information</td>
<td>3</td>
<td>4.1</td>
</tr>
<tr>
<td>8</td>
<td>Engineering, Construction and Architectural Management</td>
<td>3</td>
<td>4.1</td>
</tr>
<tr>
<td>9</td>
<td>Journal of Construction Engineering and Management</td>
<td>3</td>
<td>4.1</td>
</tr>
<tr>
<td>10</td>
<td>Assembly Automation</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>11</td>
<td>Energy and Buildings</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>12</td>
<td>International Journal of Construction Management</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>13</td>
<td>Sustainability (Switzerland)</td>
<td>2</td>
<td>2.7</td>
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<tr>
<td>14</td>
<td>Advances in Civil Engineering</td>
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<td>1.4</td>
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<tr>
<td>15</td>
<td>Australian Journal of Basic and Applied Sciences</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>16</td>
<td>Autonomous Robots</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>17</td>
<td>Buildings</td>
<td>1</td>
<td>1.4</td>
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<tr>
<td>18</td>
<td>Canadian Journal of Civil Engineering</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>19</td>
<td>Engineering Management Journal</td>
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<td>1.4</td>
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<tr>
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<td>Energy</td>
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<tr>
<td>22</td>
<td>Indian Concrete Journal</td>
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<tr>
<td>23</td>
<td>International Journal of Intelligent Information and Database Systems</td>
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<td>1.4</td>
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<tr>
<td>24</td>
<td>International Journal of Managing Projects in Business</td>
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<td>1.4</td>
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<tr>
<td>25</td>
<td>International Journal of Production Research</td>
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<tr>
<td>26</td>
<td>Journal of Architectural Engineering</td>
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<td>1.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>74</td>
<td>100</td>
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# Appendix 2. Themes and summary of overarching research questions/aims/objectives

<table>
<thead>
<tr>
<th>#</th>
<th>Thematic area</th>
<th>Summary of overarching research questions/ aims/ objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Barriers to adoption and use</td>
<td>- What factors are the key barriers to the adoption and use of OSM?</td>
</tr>
<tr>
<td>2.</td>
<td>Benefits of using OSM</td>
<td>- What are the benefits of using OSM for construction project delivery?</td>
</tr>
</tbody>
</table>
| 3. | Sustainability (climate and environment) issues | - What sustainability targets can be achieved using OSM?  
- How can OSM be used to achieve sustainability targets in organisations, on projects and for the wider society? |
| 4. | Component production (manufacturing)       | - How can manufacturing processes be optimized for component production?  
- How to optimize decision-making for component production?  
- What mechanisms can be used to reduce geometric/dimensional variability of manufactured components?  
- Design alternatives/approaches to improve component production  
- How defective can buildings constructed out of offsite manufactured components be? |
| 5. | Concept analysis                          | - How can conceptual and practical clarities about modularity be exploited?  
- What are the differences between the concepts of industrialized building and modern methods of construction across geographies? |
| 6. | Policy                                    | - What is the role of policy in driving the adoption of manufacturing approaches and modern technologies in the construction industry? |
| 7. | Project planning                          | - What design and production strategies can be used on projects where OSM is the construction approach to achieve specific outcomes?  
- What is the optimal mix of offsite and onsite tasks to achieve best project outcomes?  
- How can resources allocation be optimized when using OSM? |
| 8. | Project implementation                    | - What manufacturing approaches can be used to achieve the best project outcomes?  
- What are the management strategies for improving construction processes when using OSM for project delivery?  
- How can offsite and onsite activities be best integrated for effective project delivery?  
- How can simulation of construction processes involving the use of OSM improve project delivery?  
- What are the design risks related to the use of OSM? |
| 9. | Enabling factors and Drivers              | - What are the enabling factors for the adoption of OSM?  
- What factors are the critical drivers informing the adoption and use of OSM? |
| 10. | Success factors                           | - What are the success factors are relevant in adopting and using OSM?  
- What are the critical success factors for setting up a manufacturing facility for component production? |
| 11. | Industry-wide impact (valuing OSM)        | - How the contribution of OSM to the overall output of the construction sector be quantified using a robust methodology?  
- What robotic and automated processes can be utilized with OSM across design, manufacturing and construction stages? |
| 12. | Technological integration                 | - What benefits can be gained by from using digital technologies with OSM for project delivery?  
- What are the key environmental performance indicators for off-site built facilities compared to traditional build?  
- What are the differences in the extent of defects identifiable in offsite built and conventional built dwellings? |
| 13. | Performance analysis                      | - What are the key environmental performance indicators for off-site built facilities compared to traditional build?  
- What are the differences in the extent of defects identifiable in offsite built and conventional built dwellings? |