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A definition and valuation of the UK offsite construction sector: ten years on

ARTICLE HISTORY
Compiled August 20, 2020

ABSTRACT
Ten years on the offsite construction (OSC) industry continues to be held high as a panacea to the inefficiencies, labour shortages and environmental impact of the construction of our built environment. Speculation concerning the gross output and the debate over the subject of value added continues. The market research questionnaires remain abundant and we have witnessed a deluge of revisions to the categorisation of the sector with some significant new contributions. Sector growth is critically linked to the availability of skilled labour, the mechanisation of manufacturing processes and data driven processes. We require a new approach to engineering education to deliver our modern workforce and cross-disciplinary education and training is of fundamental importance for the delivery of Construction 4.0. Historical financial data for the period 2000 to 2018 is presented. A breakdown of the sector, examining the standard industrial classification codes (SIC 2007), gross output and value added for each categorised sub-sector is provided. The data will continue to assist government and industry in benchmarking, labour forecasting, market research and forecasting growth and diffusion of innovative delivery of offsite built environment infrastructure.

KEYWORDS
Offsite construction; prefabrication; gross output; value added.

1. Introduction

By the time of the Crimean War (1853-1856) Britain had developed a significant technical competence and production capability for the manufacture of prefabricated buildings - ranging from modest wooden or corrugated iron huts to elaborate iron villas, churches and commercial buildings. Such buildings were exported to Australia, Africa, California, India and the Far East (Herbert 1978). Early railway companies were sufficiently large to perceive the benefits of standardizing certain whole buildings. The Great Western Railway erected standardized signal boxes, halts, and stations in Edwardian years (Powell 1980). The Forth bridge saw every steel component shaped, drilled, or planned and assembled prior to being installed on the bridge itself. The girders and tubes were said to resemble giant jigsaw pieces waiting for the final picture to emerge (Wills 2009). Offsite manufacturing saw its most significant growth period in the 1920s which came from the various building and industrial concerns responding to official encouragement to overcome shortages and high prices afflicting traditional building (Powell 1980). However, problems associated with corrosion and cost remained a challenge. Enthusiasm eventually dwindled and the industry reverted back to traditional methods. Commenting upon the conditions required for all those engaged in the construction industry to increase their efficiency, the Emmerson Report

(Emmerson 1962) highlighted the need for the implementation of a longer-term and assured government building program in contrast to using public works output as a means of a short-term economic regulator. The stop-go policies exercised in the late 1950s were implemented through a series of credit squeezes and drastic cuts in public building programs (Finnimore 1989).

The first construction robot research project commenced in 1978. The research project was sponsored by the Japan Industrial Robot Association and composed of researchers and engineers from collaborating universities, manufacturers, and general construction contractors. This work was considered to be the inspiration for the plethora of automated machines which developed in the Japanese construction and civil engineering industry (Hasegawa 2000). Taylor *et al.* (2003) described the single-task robots and integrated construction systems adopted by the Big-6 Japanese contractors. The high-rise automated construction systems utilized an array of offsite manufactured components assembled on-site with canopy type temporary factory systems. Raftery (1991) commented upon the advances in manufacturing technology and robotics that have been realized in elapsed times for shorter than the physical life of the flimsiest of buildings.

The implementation of automation and robotics in construction is not a new concept. The UK construction sector is only now beginning to realize the potential of such technology. The National House Building Council (NHBC) highlighted the growing developer investment in manufacturing facilities and modern methods of construction (MMC) products or systems and presented a broad range of case studies (Hannah and Hunter 2017). The civil engineering water sector has realized the potential of offsite manufacturing for complex water treatment installations. Weston and Livingston (2019) provided details of a two-story module water treatment building consisting of a series of process modules designed-for-manufacture and assembly principles. Such concepts are well established in the shipbuilding and offshore platform assembly and have been successfully utilized in complex mechanical and electrical installations for many years, e.g. Heathrow Terminal 5 mechanical services modules manufactured by Babcock in Rosyth, Scotland.

The allocative efficiency of the construction labour force appears to be shifting towards manufacturing environments where higher value-added activity occurs. However, there is either a reluctance to adopt capital intensive manufacturing methods and processes or the pace of innovation is inhibited by risk aversion (Pan *et al.* 2004). Bock (2015) identified the developing building component manufacturing (BCM) and large-scale prefabrication (LSP) industry as means of reducing on-site complexity and building a supply chain in an original equipment manufacturer (OEM)-like industry structure. This industry structure was highlighted as essential for the successful implementation of automated and robotic on-site factories. Transformational trends in construction within the Construction 4.0 (C4.0) framework include the use of prefabrication, 3D printing (and assembly) offsite manufacturing and automation with digital links to building information models (BIM) and cloud based common data environments (CDE) (Sawhney *et al.* 2020). The rapid expansion of advanced technologies are empowering a new digitalized construction industry which promises to increase construction productivity, quality, cost and resource-efficiency (Craveiro *et al.* 2019). However, C4.0 poses multiple challenges such as reducing fragmentation, promoting transversal integration of people, process and products, achieving higher levels of flexibility and improving the management of the project throughout the life cycle (Rivera *et al.* 2020).

The value of construction new work in Great Britain continued to rise in 2018, reaching its highest level on record at £113.12 bn; this was driven by growth in public sector work of £2.69 bn and to a lesser extent growth in the private sector of £750 million. The number of construction firms operating in the construction industry has continued to rise reaching its highest level on record with 325,736 registered firms operating in Great Britain in 2018. Employment in the construction industry has been increasing since 2014, and this has continued in 2018 with construction employment increasing by 2.8 % compared with 2017, now totalling approximately 1.36 million workers (Allcoat 2018). Construction output increased by 8.2 % in May 2020 compared with April 2020, rising to £8.25 bn, though output remains at a substantially lower level than normal compared with the all work construction output series prior to March 2020. This is shown by total construction output in May 2020 being 38.8 % (£5.23 bn) lower in comparison with the February 2020 level, which was before the impact of the coronavirus (Allcoat 2020).

Hou *et al.* (2020) presented a scientometric analysis to objectively map the scientific knowledge in the field of offsite construction. The research identified state-of-the-art technology applications and critically reflected upon the application challenges. Bock (2015) identified the indicators (growth, performance, and defect rates) that suggest conventional construction methodology has reached its limits. To overcome these limits, he recommended that future construction could make use of what other manufacturing and service industries have already successfully implemented e.g. automation and mechanization. With the imminent entrance of Sekisui Heim (Ashwell 2019) to the UK offsite construction industry in collaboration with Urban Splash, the UK housing sector is poised to witness a radical technology shift based upon the decades of innovation that have bestowed the Japanese automated house building industry.

The sector has experienced a significant re-branding with construction product manufacturers using the terms offsite or modern methods of construction (MMC) in their online marketing presence. Many construction product manufacturers and engineering services companies are adjusting the market position of their products and services to be considered as offsite, modern, and innovative. Caution must be exercised where the over-inflation of offsite sector value may be due to the incorporation of traditional construction contractors and manufacturers that have re-branded traditional construction industry services. Adapting Taylor's method (Taylor 2010), a refined definition and method for the valuation of the UK offsite construction sector from 2000 to 2018 is presented. The valuation incorporates UK registered companies and purposely ignores imports from European and international suppliers. The industry categories previously defined in 2010 and the Farmer (2016) MMC categories are considered. The historical value of the sector is examined over the period of 2000 to 2018. Data concerning the gross output and value added of offsite construction sub-sectors is provided.

The research objective was to provide an ongoing benchmark of the market valuation of the UK off-site construction sector. The data provides a long term historical analysis of the value and composition of the UK offsite prefabrication sector. The research builds upon the work of Taylor (2010) and provides a further decade of data showing the expansion of the sector and the growth of specific sub-sectors. The data are intended for use by the UK government, client organizations, trade organizations, manufacturers, suppliers, contractors, and sub-contractors who may be required to assess the development and growth of the sector. The following section reviews the terms, definitions, and categories adopted in the research method.

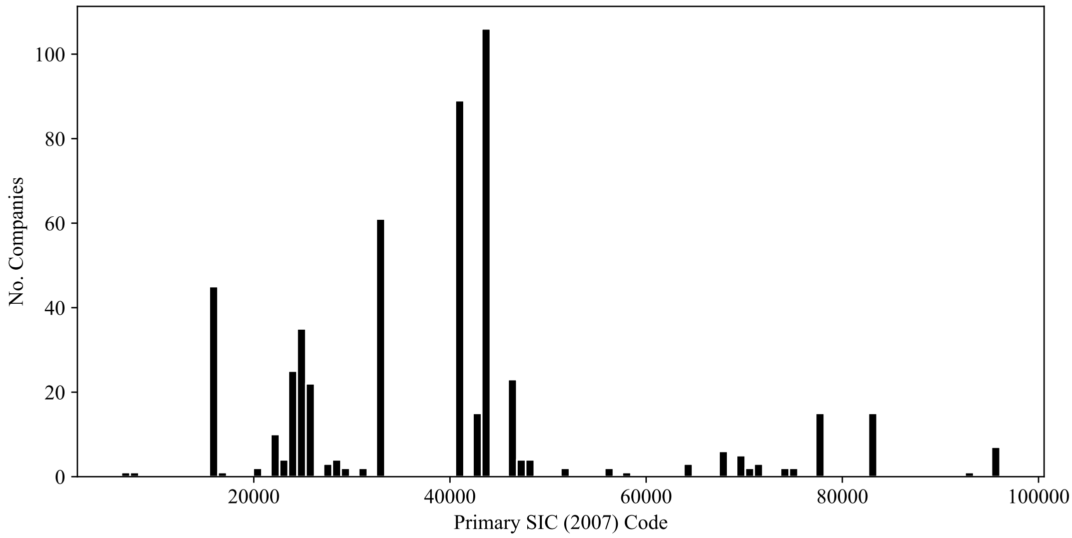

Figure 1.: Offsite construction sector SIC (2007) codes ($n_s = 579$)

2. Offsite construction: defining the industry

The definition of offsite construction (OSC) continues to be the subject of debate and ongoing fettling. Despite the established academic field of construction automation and construction robotics the industry appears to have re-branded an existing approach to the concept of industrialised building and prefabrication.

The standard industrial classification (SIC) codes for UK economic activity (SIC 2007) provides an insight into the industrial activities considered to be offsite construction. The SIC codes provide a detailed overview of the manufacturing and mechanical engineering services that contribute to the current offsite capabilities of the UK. The predominant SIC codes include:

(1) Section C: Manufacturing, Divisions 23, 24 & 25
(2) Section F: Construction, Divisions 41, 42 & 43

The SIC codes provide a detailed overview of the manufacturing and mechanical engineering services that contribute to the UK offsite construction sector. Figure 1 provides a summary of the SIC codes for the companies included in the sample frame. The building component manufacturing provision evident would suggest that we are witnessing the rise of Bock's (Bock 2015) envisaged new supply chain capability. However, we appear to lack significant innovation in the use of automation and robotics in the sub-assembly and on-site completion of buildings and structures. Very few, if any, of the SIC codes identified relate to the deployment of automation and robotics in construction.

The Secretary of State for Communities and Local Government (2017) set forth proposals for an Accelerated Construction programme aimed to catalyse changes in the wider housing market, through supporting offsite manufacturing techniques. Farmer (2016) provided a bleak prognosis for the UK construction industry in the form of a 20-25 % decline in the available labour force within a decade. The result being an inability to deliver critical social and physical infrastructure, homes and built assets required by other industries to perform their core functions. Farmer suggested initiation policy

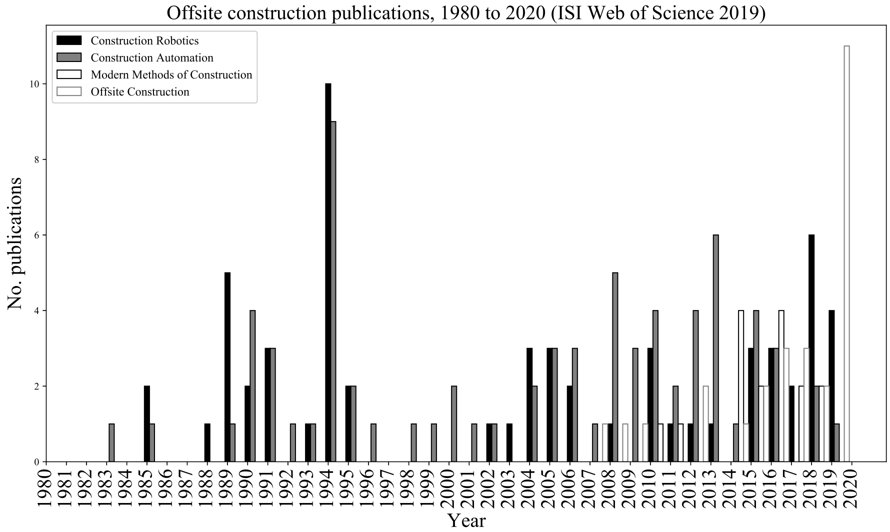

Figure 2.: Offsite construction publications between 1980 and 2020 (ISI Web of Science Categories = Engineering Civil and Construction Building Technology, n=178, 2019)

measures in the form of incentives and direct commissioning of pre-manufactured housing - a recommendation reminiscent of the Emmerson (1962) report.

The term 'pre-manufacture' has now added to the terms often attributed to the sector. 'Prefabrication' and 'industrialised building' terms are commonly associated with the historical failures of the 1960's attempts to industrialise and modularise approached to commercial, educational and high dwelling infrastructure. Warszawski (1999) referred to the industrialised building techniques that replaced human labour on site and eliminated waste. He also described the use of automated machines to assist in the construction of industrialised building elements and components. Figure 2 shows the development in terminology trends considered over the period 1980 to 2020. As we re-brand the concept of innovative construction we attempt to convince the home owner of the modern techniques they are investing in. However, with defects and snagging continuously blighting the domestic dwelling construction sector it is not difficult to see why innovation is so urgently required.

3. Valuation method

A purposive non-random sample of companies associated with the UK offsite construction sector was obtained. To obtain the purposive sample, the research was considered the following sources of data:

(1) Published supplier directories, approved manufacturer lists and members of related trade organisations.
(2) Financial accounts for UK registered companies.
(3) National construction industry output statistics.

The following lists of offsite suppliers were specifically targeted to be compile the sector population sample frame:

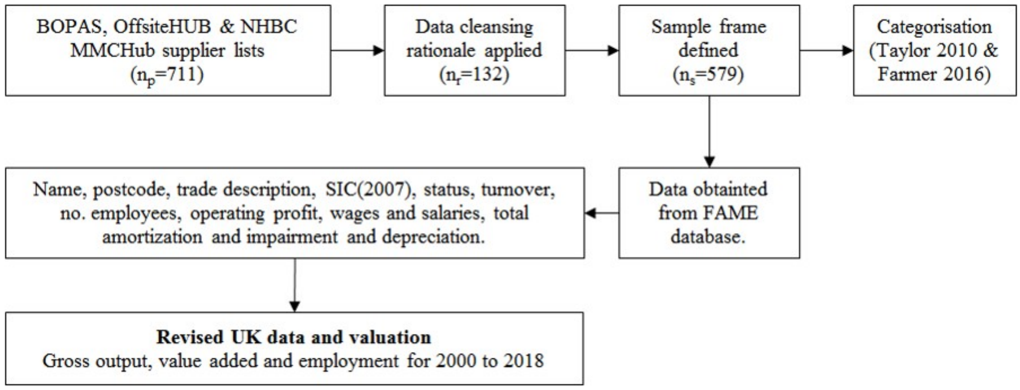

Figure 3.: Valuation method.

(1) OffsiteHub supplier directory.
(2) BOPAS accredited designs, manufacturers and constructors.
(3) NHBC MMCHub accepted MMC systems.

The OffsiteHub is an online information centre providing information and news in the offsite construction sector. The centre publishes an online supplier directory which provides a list of manufacturers and suppliers of offsite construction service providers. The Buildoffsite Property Assurance Scheme (BOPAS) was developed to provide assurance to the financial services community that non-traditional and innovatively constructed dwelling systems will be readily saleable for a minimum of sixty years (BOPAS 2019). The assurance scheme in includes Lloyd's Register process accreditation, BLP durability and maintenance assessment and a website listing which details the assessed organisations. The National House Building Council (NHBC) conduct reviews of MMC systems that builders are proposing to use and assess if they are acceptable for use in dwellings covered by the Buildmark warranty scheme. A list of accepted MMC systems is published online in conjunction with recent MMC research and innovation information (NHBC 2019).

The supplier sample frame data is provided in Table 1. The offsite supplier lists provided a total of 711 (n_p) companies. Following data cleansing a total of 579 (n_s) companies were selected as the sample frame for the present study. Details of the data cleansing rationale and the number of companies removed from the sample population are provided in Table 2.

The cleansing rationale was applied to ensure that the valuation included the active OSC sector at the time of data compilation. The supplier directories included duplicate entries and subsidiaries of parent companies that were already incorporated. Companies considered to be offering traditional architectural or engineering design services were excluded as they were deemed not to be solely providing offsite construction services. Companies not registered in the United Kingdom were removed. However, these companies do provide components, products and systems that would be considered as a contribution to the UK OSC sector - the subject of imports is beyond the scope of a UK OSC sector valuation.

Financial accounts were obtained for the sample frame ($n_s = 579$) over the period 2000 to to 2018. Data was obtained from the Bureau van Dijk FAME database. The financial performance data obtained represented a true and fair view of the companies

Table 1.: Population and sample frame data summary.

Description and notation	**No.**
Sample population, n_p	711
Companies removed by cleansing, n_r	132
Sample frame, n_s	579

Table 2.: Data cleansing rationale.

Cleansing rationale	**No.**
Duplicate record	23
Subsidiary of parent company already included	8
Traditional architectural or engineering design	5
Non-UK registered company	26
Traditional construction and civil engineering	4
Company operations not relevant	53
No companies house data available	8
No contribution during 2000 to 2018 period	5
Total removed from sample population	**132**

status and complied with Financial Reporting Council regulatory framework. As highlighted by the method previously adopted by Taylor (2010), the data obtained was not open to misrepresentation and exaggeration often obtained by survey questionnaire responses where companies aim to improve their corporate image and demonstrate superior production capacity. Figure 3 depicts the process adopted in the compilation of the valuation data. The company accounts obtained a substantial amount of information that was not deemed to be relevant to the present study. Data was selected using the FAME database analysis options and exported as a series of .csv files for further analysis using Python modules including Pandas dataframes, Numpy and data visualisation using Matplotlib.

Two measures of output were adopted:

(1) Gross output - records the sum of all values of sales by all firms in the defined sector ($n_s = 579$) and corresponds to notions of turnover or sales.
(2) Value added - records the value added by the company to the value of inputs received from their supply chain.

Gross output is a useful measure of the general level of economic activity in an industrial sector. However, value added is the more relevant measure since it indicates the overall contribution of the offsite construction sector to the UK gross domestic product . The method of calculating value added is shown in Equation 1:

$$\begin{aligned} Value\ added = {} & operating\ profit\ (before\ tax) + employee\ costs \\ & + depreciation + amortization\ and\ impairment. \end{aligned} \tag{1}$$

Operating profit is defined as the turnover minus the cost of sales, employee costs, depreciation and other overheads. The employee costs will include national insurance contributions and pension contributions. Amortisation is the writing off or depreciation of goodwill and other intangible assets and was reported in the company accounts obtained. Amortisation is often not available in company accounts as it is considered to not be relevant. The value has been included in the calculation for completeness

Table 3.: Offsite and Farmer MMC categories, definitions and comparison of sub-sector companies (2010 and 2019).

Offsite category	**General description**	**MMC[a]**	**2019**	**2010[b]**
Bathroom/kitchen pods	Volumetric modules	1	20	8
Cladding and faade	Modular faade systems	5	57	21
Components	Ducting, fitting and windows	6	49	13
Light steel frame	Cold formed steel	2	30	17
Merchants	Construction components	6	10	5
Pre-cast concrete	Offsite systems	3	43	15
Pre-engineered M& E systems	Modular M&E systems	5	48	35
SIPS	Structural insulated panels	2	19	10
Timer frame (closed panel)	Sheathing,insulation and M&E	2	11	6
Timber frame (general)	All timber frame	2	95	3
Timber frame (open panel) [c]	Traditional open panels	2	2	33
Timber frame (structural elements)	Beams, trusses and elements	6	22	20
Volumetric (permanent)	Non-relocatable modular buildings	1	56	14
Volumetric (temporary)	E.g.site accommodation buildings	1	75	22
Miscellaneous	Design services, special trades	6	42	23
		n_s	**579**	**245**

[a]Farmer (2016) Category 1 = Pre-Manufacturing - 3D primary structural systems, Category 2 = Pre-Manufacturing - 2D primary structural systems, Category 3 = Pre-Manufacturing - Non systemised structural components, Category 4 = Pre-Manufacturing - Additive Manufacturing, Category 5 = Pre-Manufacturing Non-structural assemblies and sub-assemblies, Category 6 = Traditional building product led site labour reduction/productivity improvements and Category 7 = Site process led labour reduction/productivity improvements (not considered).[b]Taylor (2010). [c] Open panel timber frame manufacturers categorised in 2019 as 'general' timber frame providers.

(O'Connor 2018).

4. Categorisation

The categorisation of the OSC sector was undertaken using the categories and definitions identified by Taylor (2010) and the MMC categories identified by Farmer (2016). Table 3 shows a summary of the sample frame categorised using the definitions identified. Table 4 and Table 5 show the OSC sector gross output and value added over the period 2000 to 2018. Table 6 shows a summary of the status of the companies identified in the sample frame (n_s). A total of 382 companies were recorded as being active in 2019. The remaining companies were included in the sample frame as they have contributed to the offsite construction sector gross output over the time period considered (2000 to 2018).

5. Results

The sector gross output for the period 2000 to 2018 is presented in Figure 4. Figure 5 shows a combination of the gross output, value added and total employment for the same period. Following the 2008 recession, the gross output remained relatively stable with growth commencing from 2013 (£5.05 bn) and levelling off in the years 2016 (£6.68 bn) to 2018 (£6.78 bn). This coincided with a significant increase in employment. The 2018 OSC sector gross output was £6.78 billion and the value added was £1.735 billion. In 2018, the overall contribution to the UK GDP was £1.73 bn which represented represented 5.9 % (£6.78 bn) of the value of all UK new work (£113.12 bn).

Table 4.: Offsite categories gross output (GBP millions).

Offsite Categories	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Bathroom/kitchen pods	18.53	28.00	31.93	20.24	40.82	29.61	28.51	35.20	35.06	17.04	0.00	0.00	29.31	19.30	34.82	35.95	45.16	61.74	70.09
Cladding and facade	292.05	317.57	329.15	375.85	384.03	365.28	399.55	406.34	432.66	373.97	410.27	415.73	475.91	489.17	615.45	679.58	926.49	803.30	908.93
Components	325.03	321.78	371.28	358.62	371.50	439.32	491.38	458.78	568.65	425.28	415.47	450.49	440.81	467.13	514.93	516.99	613.89	571.01	473.25
Light steel frame	102.98	92.87	90.31	80.89	98.84	119.14	133.31	140.60	159.83	127.69	114.93	124.48	141.20	113.78	117.64	131.13	139.84	162.18	180.75
Merchants	86.88	103.32	111.23	134.47	168.31	202.09	223.47	309.61	337.64	275.60	255.43	260.67	260.98	226.39	328.98	339.18	370.69	404.26	288.55
Pre-cast concrete	114.04	136.24	153.97	175.38	586.28	619.31	655.93	593.22	595.20	521.91	647.10	771.21	807.85	837.48	1020.97	1287.09	1367.41	1452.55	1583.53
Pre-engineered M&E systems	675.60	825.83	831.26	809.55	824.84	936.40	1124.22	1203.53	1507.73	1604.44	1422.78	1348.78	1402.18	1368.40	1358.04	1394.71	1349.79	1402.10	1221.60
SIPS	0.00	0.00	0.37	0.00	13.76	18.78	21.79	19.06	22.54	32.62	20.66	21.32	15.77	26.04	24.12	24.89	32.69	29.14	27.48
Timer frame (closed panel)	16.93	22.96	17.26	23.61	36.49	49.40	48.79	63.10	42.97	37.27	44.85	45.38	38.78	44.47	28.41	22.75	18.70	20.96	18.79
Timber frame (general)	162.42	188.58	195.96	252.67	310.33	352.64	470.52	554.32	585.13	385.45	371.16	344.38	380.59	338.14	338.36	432.84	431.43	454.23	513.71
Timber frame (structural elements)	212.52	214.34	280.56	304.81	339.77	351.22	364.29	390.74	378.01	337.40	342.19	365.07	332.67	325.94	328.55	334.12	345.22	341.66	323.82
Volumetric (permanent)	82.52	97.26	115.35	131.38	169.43	223.80	169.72	186.33	220.87	227.42	191.15	142.11	139.50	138.76	123.84	187.26	234.94	271.10	334.94
Volumetric (temporary)	221.85	261.17	287.91	344.22	331.92	333.60	377.93	336.86	364.51	504.11	459.24	554.94	562.65	603.69	603.57	742.45	706.74	700.07	767.23
Miscellaneous	63.54	60.39	67.81	70.42	70.28	77.66	63.80	68.72	84.79	87.29	88.83	70.37	53.11	60.14	70.87	97.90	100.40	72.62	76.81
TOTAL Gross Output (turnover)	2374.88	2670.31	2884.36	3082.11	3746.60	4118.22	4573.20	4766.41	5335.59	4957.49	4784.05	4914.93	5081.31	5058.84	5508.54	6226.83	6683.38	6746.91	6789.48

Table 5.: Offsite categories value added (GBP millions).

Offsite Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Bathroom/kitchen pods	0.58	1.44	4.03	4.02	3.88	1.55	1.06	2.26	0.31	0.37	0.02	0.00	11.26	7.50	13.02	13.36	19.55	27.46	26.20
Cladding and facade	30.77	40.04	81.24	94.55	91.14	98.73	100.95	96.24	101.29	82.90	87.73	86.84	98.66	95.04	127.14	164.31	245.38	234.36	253.16
Components	38.99	32.26	94.83	87.42	91.33	97.34	127.42	121.85	128.34	99.28	113.63	115.61	113.12	117.77	133.49	140.80	198.21	144.71	97.70
Light steel frame	5.81	8.28	20.60	24.84	33.66	38.74	46.19	54.81	62.95	51.11	23.15	36.78	45.88	34.30	36.75	42.48	51.15	56.02	54.36
Merchants	2.82	3.21	12.65	17.45	22.95	30.47	32.46	50.53	50.37	29.19	24.39	23.97	21.14	21.38	31.35	32.15	36.73	39.10	35.37
Pre-cast concrete	11.12	17.51	32.71	57.81	219.10	206.73	227.92	220.51	227.06	172.27	193.04	158.73	172.38	200.04	279.60	410.94	430.29	462.41	518.20
Pre-engineered M&E systems	20.95	21.30	117.30	224.88	231.83	244.13	260.98	282.92	296.11	306.80	290.72	233.99	260.98	241.16	247.94	240.80	256.67	267.15	237.36
SIPS	0.00	0.00	-0.05	0.00	4.16	3.96	5.73	5.86	5.73	8.22	1.96	4.06	3.42	4.66	4.30	4.27	5.65	6.60	6.20
Timer frame (closed panel)	0.11	-0.31	1.20	3.39	6.20	9.99	7.12	9.88	8.77	7.63	9.33	7.17	6.44	8.03	4.32	2.66	3.78	3.70	2.67
Timber frame (general)	10.96	13.06	51.87	65.13	74.52	89.00	128.98	137.08	123.89	53.71	74.53	66.71	68.50	64.59	71.47	84.07	82.50	97.64	110.99
Timber frame (structural elements)	11.50	12.86	41.56	54.53	63.73	61.59	58.92	61.78	55.32	57.88	50.63	60.98	59.13	53.24	50.40	58.10	64.53	55.67	53.80
Volumetric (permanent)	4.69	8.05	20.76	33.20	38.46	51.47	41.96	45.81	52.90	44.20	34.55	13.04	21.11	14.90	22.10	40.16	37.45	14.26	47.34
Volumetric (temporary)	37.76	48.19	105.65	130.92	112.15	123.02	122.55	116.61	155.49	192.29	165.26	158.61	181.14	173.59	188.81	247.63	233.45	277.38	276.79
Miscellaneous	5.25	6.95	17.03	17.03	15.62	12.38	11.56	16.79	21.48	21.22	13.48	11.56	9.66	9.78	13.58	31.31	30.09	17.23	15.25
TOTAL Value Added	181.31	212.84	601.37	815.15	1008.73	1069.09	1173.80	1222.93	1290.00	1127.06	1082.42	978.02	1072.82	1045.97	1224.27	1513.03	1695.44	1703.69	1735.39

Table 6.: Company status, 2019.

2019 Company status	**No.**
Active	382
Active (dormant)	40
Active (dormant), in default	1
Active, in administration	3
Active, in default	1
Active, with vol. arrangement	3
Dissolved	135
In liquidation	14
Total sample, n_s	**579**

Table 3 provides a comparison of the the offsite sub-sectors in 2010 (Taylor (2010)) and 2019 (present study). The results show that there has been an increase in the providers of modular facade systems, components, light steel (cold formed) frame, timber frame and volumetric buildings (both temporary and permanent). However, examining company operations it is evident that the expansion of the number of offsite manufacturers is related to re-branding and alternative marketing of traditional factory manufactured products and components. A more detailed study of the labour force would confirm the presence of new employment or the re-deployment of construction industry workforce into manufacturing sectors.

Table 6 summarises the operational status of the companies considered, with only 382 companies active as of 2019. Having only considered active companies, the calculated gross output for the OSC sector was lower that the 2010 valuation (Taylor 2010). The valuation variation was predominantly due to the revised cleansing rationale adopted for the present study. The sector remains volatile with a significant number of companies being either dormant, dissolved or in liquidation over the time period considered.

The offsite construction sector remains as a combination of traditional materials, component manufacturers and building element manufacturers which combine to offer their service provision to meet the increasing demand for offsite manufactured components and systems. The supplier lists available do not include a range of manufacturing sectors which may may have been contributing automated machinery, robotic manipulators or data driven services including BIM and cloud computing. Figure 6 shows that Farmer (2016) categories non-systemised strucutural components (Category 3) , non-structural sub-assemblies (Category 5) and traditional site led building product labour reduction improvements (Category 6) represent the majority of the value added by existing offsite sector manufacturers and service providers. However, 3D primary structural systems (Category 1), 2D primary structural systems(Category 2) additive manufacturing (Category 4) and site based production improvement techniques (Category 7) are either developing sub-sectors or represent significant growth opportunities (Category 4 & 7). The supplier lists used to compile the sample frame do not include such manufacturing sectors which may could be currently providing automated machinery, robotic manipulators or data driven services including BIM and cloud computing.

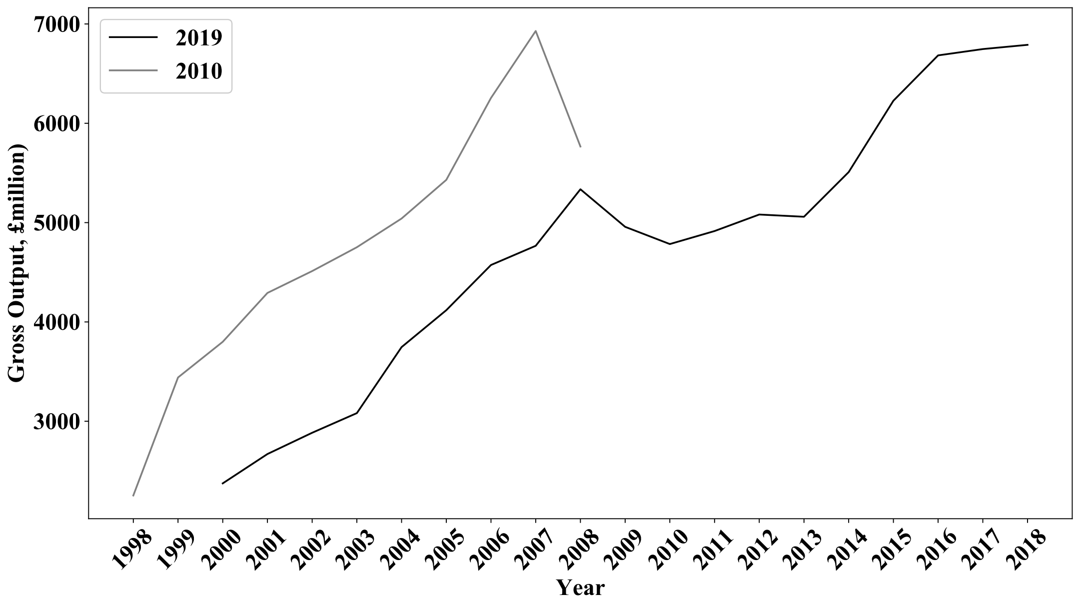

Figure 4.: Offsite sector gross output including Taylor (2010) valuation.

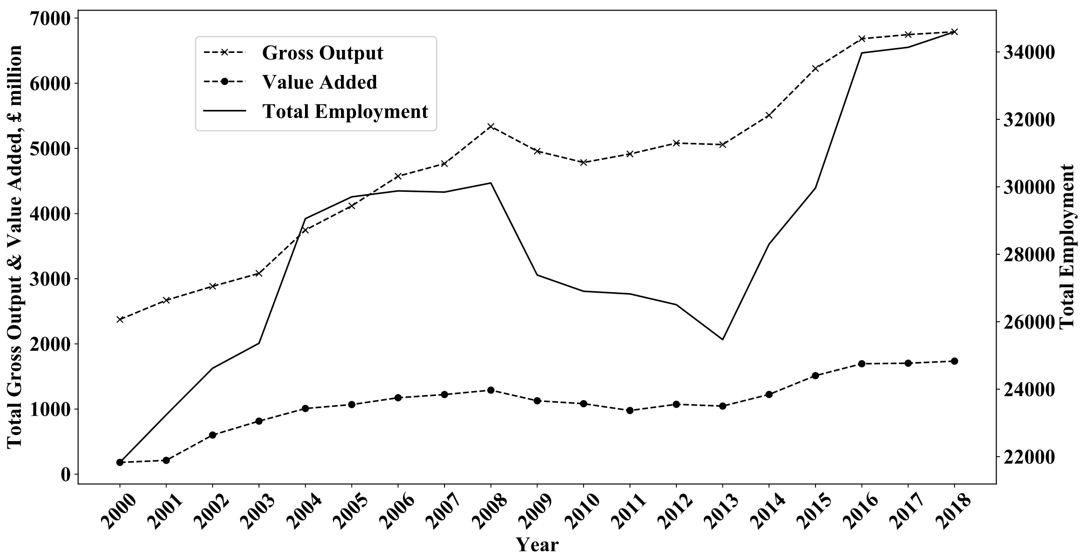

Figure 5.: Offsite sector gross output, value added and employment.

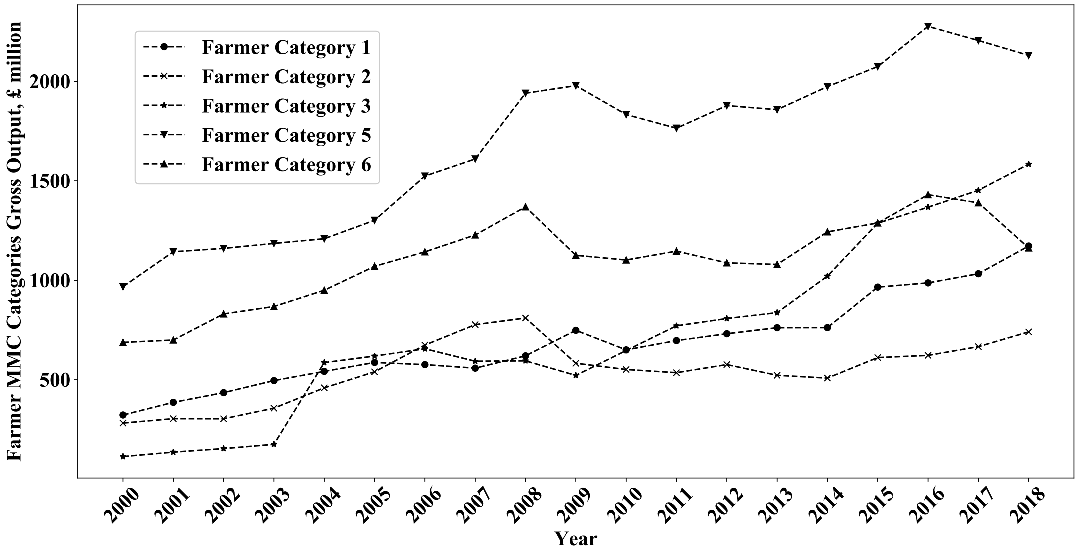

Figure 6.: Farmer MMC category output.

6. Discussion

The offsite construction sector consists of a broad range of industrial and engineering sectors metamorphosing into providers of what is considered innovative and modern construction methods. Many of the companies considered in the present study represent long established service providers to the house building, construction and civil engineering sectors. A combination of re-branding and marketing as 'offsite' or 'modern methods of construction' suppliers has created a considerable restructuring of the construction industry supply chain. However, there has been limited attention to capital expenditure associated with mechanised and automated production facilities. The lack of investment in fixed capital is directly associated with the political and economic instability associated with the house building and construction sector. The government demands significant construction of new affordable housing and the demands of the 1962 Emmerson report remain true today.

The sector remains volatile with a significant number of companies being either dormant, dissolved or in liquidation over the time period considered. The research has highlighted that there has been significant growth in the level of innovation in the construction sector with a general increase in manufacturing capacity some subsectors. However, we have seen the expansion of the number of traditional offsite manufacturers and a significant amount of re-branding and alternative marketing of traditional factory manufactured products and components.

The investment of Japanese housing manufacturers in UK developments has commenced and the rise of highly competitive and highly experienced offsite manufacturers is set to revolutionise the industry. Building upon the decades of experience in international markets, these providers will hopefully continue investing in UK based production facilities. The use of the construction industry as a regulator of employment and the the displacement of work activities remains a concern. However, many of the trade skills required on-site can be applied to manufacturing production environments. The labour force shifting to manufacturing facilities may improve working conditions and provide opportunities for training and development often difficult to undertake when working at construction site locations. The industry is clearly at the brink of significant technological shift - and the political will is evident through the recent appointment of the government modern methods of construction champion.

Further research should consider the contribution of international manufacturers and service providers that contribute to the UK built environment. In particular, it should consider the value of offsite construction and manufacturing in other developed nations with specific attention to the value of exports to the UK construction sector. Furthermore, the digital transformation that these international manufacturers and service providers have undertaken should be studied with particular attention to adoption of digital technology, implementation of embedded system production, smart production processes and the adoption of radical process changes as adopted in automotive, aeronautical and ship building industries. The shift towards a physical-to-digital-to-physical connection enabled by the use of sensors, augmented reality systems, high performance computing, additive manufacturing, advanced materials, simulation and autonomous robotics (Craveiro *et al.* 2019) should be the ongoing focus of the UK offsite construction sector.

Innovation hubs and centres are appearing across the country. Static robotic manipulators are being used for a range of timber engineering projects in Scotland - including the manufacturing of innovative structural connections. Established contractors are tentatively investing in manufacturing facilities. The rise of automated production lines is only achievable is high volume orders are maintained to justify such capital investment - which presents a challenge. The establishment of high capacity manufacturers operating in the UK is becoming evident - will we see the rise of highly competitive manufacturers that will eliminate the traditional building techniques? There remains a significant demand for the flexibility associated with cut-to-fit traditional construction build techniques and materials. Over the last ten years the UK offsite construction has not witnessed the radical changes that were anticipated. Clients demands for improved efficiency and quality remain - but the industrialised and automated construction industry remains illusive.

7. Conclusions

The offsite construction sector continues to struggle to improve its overall performance and contribution to the UK construction sector - reaching a gross output of £6.78 bn in 2018. The research contributed to the ongoing assessment of the value and contribution of the off-site construction sector to UK GDP. In 2018, the sector gross value added was £1.73 bn. Contributing 5.9% of all new construction work (2018) there appears to be the potential for significant growth. It is essential that the construction industry, trade organisation and labour forecasting bodies use accurate, reliable and valid data in assessing the resource requirements for growth in the UK OSC sector.

The research contributed a robust and accurate method for the valuation of the UK OSC sector. The results may contribute to corporate decision making and ongoing monitoring of the future expansion of offsite construction techniques, processes and technical solutions. The research does not provide growth forecasts, but provides a suitable baseline method for forecasting of labour requirements and growth.The method presented provides a repeatable and accurate long term review of the gross output and value added by the sector.

The offsite construction sector has expanded in relation to the number of manufacturers that consider themselves to provide innovative services. There now must be a reorientation towards greater automation, mechanisation, cloud computing, additive manufacturing, sensors and information modelling. Sector growth will be built upon rise of new integrated service providers with alignment with C4.0 capabilities. However, lean construction, building information modelling and integrated project delivery must remain the focus of attention for attaining C4.0 working standards. The education and training of the new workforce has significant implications for curriculum design for further and higher education providers. It is critical that new vocational and degree programmes consider construction and civil engineering integrated with computer science, mechatronics and manufacturing principles.

The expansion of experienced international industrialised building providers into the UK sector will provide a significant disruptor and initiate a new order amongst traditional suppliers, sub-contractors, offsite manufacturers, main-contractors and developers. The fragmented and traditional construction industry is experiencing a new industrial revolution with the potential for considerable educational and technological reconfiguration. 'The robots will make bricks and houses for us' (Capek 1923).

Acknowledgements

The author wishes to thank Mohammed El-Haram and Davide Vitali for the discussion and debate surrounding the development of the research method adopted. Particular thanks are due to Lisa Macdonald for her support during the research.

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