Increasing need for Offsite Construction and Manufactured Infrastructure in the UK Economy

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***Abstract*—Due to increasing demand for housing and other building infrastructure the methodology of offsite construction is becoming more attractive to developers, local authorities and government organisations. This paper outlines some of the key drivers such as on-site skills shortages, increasing population, community and education buildings required and policy issues. Collectively they provide a demand platform, which requires a paradigm shift towards 'infrastructure by manufacture' such as offsite. Offsite construction techniques provide a range of benefits, which can embed manufacturing and supply chain routes in future economic growth across the UK and deliver a more sustainable approach.**

Keywords— offsite construction; low carbon; building technologies; skills; manufacturing; infrastructure.

I. Introduction – Offsite Construction

Offsite construction is defined as the manufacture and pre-assembly of components, elements or modules before installation into their final location (1). Offsite construction is one of the approaches within the overarching terminology of Modern Methods of Construction (MMC), whereby MMC is the continuous improvement of building processes through the application of lean theory to remove waste and increase value.

Offsite construction for buildings typically involves the incorporation of one or more of the following offsite systems:

- Closed panel construction for walls and roof systems
- Cassette floor systems
- Bathroom pods and kitchen modular units
- Roof modular units
- Whole room modular units
- Whole building modular units

Generally the level, complexity or category of offsite is dependent on the extent of pre-assembly of the components offsite, such as installation of insulation, wall linings, membranes and connections for services.

Whilst offsite construction has been initiated by various companies during the last three decades interest in the sector has gained traction during the last 5 years by government departments initiating various reviews, consultations, commissioning reports and supporting skills development.

In 2012 the UK government commissioned the 'Offsite Housing Review'(2), to identify how offsite construction could be supported, identifying the future benefits gained from offsite and how this could inform future parliament budget announcements and investment. The UK offsite

sector in 2012 was valued at £1.25 billion with anticipated growth to £6 billion over the coming years (7% of £90 billion construction market).

In 2012 the Scottish Government commissioned a 'Strategic Review of the Offsite Construction Sector in Scotland' [3]. This identified from interviews with 17 offsite manufacturing and key system suppliers an annual value to the economy of £135 million (manufacturing base) with expected growth to £260 million by 2018. This report led to the Scottish Government investing in the Greener Homes Innovation Scheme investing in new housing developments, which incorporated offsite construction techniques.

In 2013 the UK Commission for Employment and Skills (UKCES) published an evidence report 'Technology and Skills in the Construction Industry' [4] which built upon the previous 2012 publications such as 'Sector Skills Insight' [5] and 'Sector Skills Assessment for Construction' [6].

In 2014 the UKCES launched a competition [7] whereby organisations could apply for a proportion of funding to support the development of offsite skills. Five projects were successful in securing this funding and the project leads were:

- Laing O'Rourke – concrete offsite systems
- Steel Construction Institute – lightweight steel offsite systems
- Skanska – offsite construction school
- The Comparator Project – comparing whole life costs and sustainability metrics through an online design software
- Edinburgh Napier University – practical and interactive learning materials with strong focus on timber based systems

The Scottish Government Skills Development Plan 2014, published by Skills Development Scotland [8] also identified Offsite as a key growth area and necessity for future skills training. Resource Efficient Scotland and Zero Waste Scotland have also supported and trialled offsite systems, at the BRE Innovation Park at Ravenscraig. Industry bodies such as BuildOffsite[9] have grown in membership and improved warranty and insurance measures have been developed for the sector.

Such approaches to develop skills and deliver underpinning support measures have come at a crucial time for the industry given the strategic future role this sector could provide in the delivery of building infrastructure over the coming decades.

II. Key Drivers

A series of external drivers are playing an integral role in how the future use of offsite is gaining traction with key stakeholders. These drivers are primarily linked to:

- supply shortages in skilled workforce
- current and future population changes,
- demands upon the UK's retirement and care habitat,
- education buildings, and
- sustainability measures.

A. Future work force

The collective influence of the UK economic downturn led to approximately 57,000 school leavers not entering the construction sector and choosing other industry sectors. The combined effect of the loss of key skilled workers during the recession, reduction in overall apprenticeships numbers and lack of school leavers choosing construction related degrees would limit the future outputs and growth for the sector.

During 2014-15 surveys by the Federation of Master Builders [10] identified key shortages for on-site skills. 25% of companies had reported significant difficulties in recruiting for: bricklayers; joiners; site managers; supervisors; plumbers; plasterers; roofers and HVAC services staff.

For companies to meet future contracts and for governments to deliver significant housing growth a step change approach is required to address such skill shortages.

B. Population changes

According to the United Nations Department of Economic and Social Affairs[11] the global population increases by 1.5 million people per week. The UK population of 64.6 million is ranked 22nd in the world for population by country.

By 2039 the UK population is estimated by the Office for National Statistics[12] to increase by 9.7 million to a total of 74.3 million. This will place significant pressures on existing societal infrastructure such as housing, schools and health care.

A population increase of 9.7 million during the 80's and early 90's, with 2.4 people per household, would have required approximately 4 million new homes. However, current UK average household sizes are decreasing towards 2.2, which would require 4.3 million homes to be built between 2017 and 2037. This translates to 220,000 new homes per year every year. In addition, there are 1.5 million households on UK housing waiting lists [13,14] due to either living in very poor condition housing, staying in temporary accommodation or living in very overcrowded homes. If 75,000 additional homes were built each year (5%) to start to address the housing waiting lists, the total number of new homes required to be built would be 295,000 per year till 2037.

In the shorter term till 2022 the Office for National Statistics estimates population increases across the English regions, with the main increases primarily focused in London, East and the South East. Whilst Scotland's population is projected to increase by 7.5% over the next 20 years Edinburgh's population is anticipated to increase by 21% [15].

A key change the UK and other developed countries are facing is the demographic change to population. The increasing proportion of certain age groups, changes in living style and reduction in the number of people per household will place significant demand on the future supply of societal infrastructure such as housing and health care. With people living longer and requiring use of societal infrastructure over an extended period this will impact on future housing needs, designs and building technologies.

By 2037 25% [16] of the UK population will be aged over 65 years. Increasing life expectancy, people marrying later in life and divorce rates leads to an additional pressure beyond only population changes occurring.

Statistics from the Scottish Government show an expected 9% increase in population from 2012-37. However, the number of households during the same period will increase by 17%, as outlined in Fig 1.

Scotland	**Period**
Type of increase	2012-37
population increase	*9%*
households increase	*17%*

Fig. 1 Comparison of household versus population increase 2012-37, Scotland. [17]

The influence of changes over the last 30 years in 'household size' is shown starkly by the change in '1 and 2 person' households, outlined in Fig 2. This provides supporting evidence towards future household projections and anticipating future trends and pressures UK governments must meet.

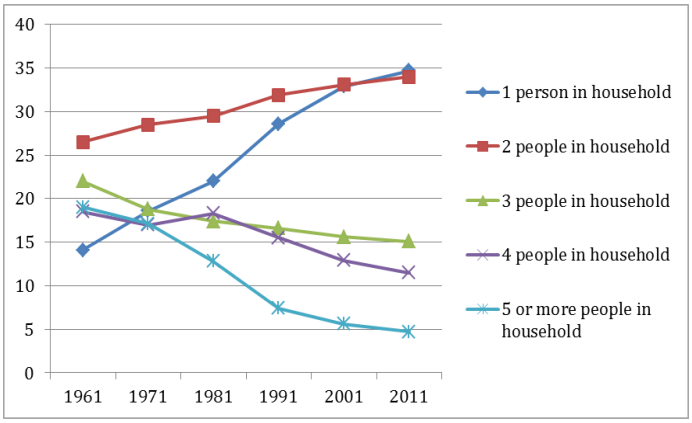

Fig. 2 Variations in household size during the last 30 years. [18]

C. Retirement infrastructure

Increasing life expectancy also results in greater provision of care for communities in urban or rural communities. Currently there are 18,000 retirement and care home buildings in the UK housing 30 to 70 occupants. With the number of over 85's set to double in the next two decades significant pressures on housing and care provision will occur.

Residential demand for care homes will rise [19] from 440,000 to 824,000 beds by 2040. From recent studies by Smith [20] the UK would require to build 15,500 care and retirement buildings by 2035, each housing an average of 55 occupants, resulting in 780 to be built every year.

D. Education infrastructure

In England there are 16,766 state primary schools and 3,381 state secondary schools [21]. Over the past six years England invested £20 billion in the new school buildings. Lessons are being learnt from the previous 'Building Schools for the Future' program where only 25% of the first 200 schools had been delivered[22] within the expected timescale. Central and local governments are likely to focus in future on greater use of offsite construction techniques for school building projects.

Whilst there has been considerable investment in new schools there are still significant proportions of the existing school building stock which will require to be replaced and upgraded. Fig 3 shows the period of build in England and the proportion of the school building stock gross floor area built during these periods. 45% of the building stock stems from pre-1966, 23% between 1966-76 and 2% temporary, which were originally designed for short term measures. Many temporary school buildings over time became permanent structures. This has led to higher costs for local authorities as these buildings often require significant maintenance or have to be closed due to leakage leading to lost education time.

School Building Period	% of Gross Floor Area
Pre 1919	12%
Inter War	8%
From 1945-1966	25%
From 1966-1976	23%
Post 1976	30%
Temporary	2%

Fig. 3 Period of school building stock in England. [21]

There are currently 2,048 primary schools and 362 secondary schools in Scotland. 20% of the building stock has been renewed or refurbished over the last 10 years. Recent statistics on ratings of Scottish school buildings show that 422 schools are in 'poor' condition and accommodate over 104,000 pupils [23].

Whilst governments and local authorities try to address the growing population and new schools required there are ongoing pressures regarding replacement and upgrading of the existing education infrastructure. The construction sector has one of the lowest productivity rates of all sectors, whereas manufacturing has the highest [24]. As such a future shift towards 'manufacturing infrastructure and buildings' could improve productivity, reduce cost variables and improve the construction management process.

E. Sustainability and material resources

The number of sustainability, waste reduction and other carbon measures developers and local authorities need to address has also led to modifications towards the future whole build approach.

Offsite construction has a range of benefits relating to reduced waste on site, better quality control, energy efficiency, better logistics and pre-planning approach and speed of build when compared with normal on-site build activities.

One aspect which is often cited by the offsite sector is the reduction in transport to site of products and

materials and also on-site traffic. Studies by Quale [25] in 2011 compared traditional onsite versus offsite and CO2 emissions. Quale showed that offsite based sites reduced transport emissions by up to 60% and when taking into account the delivery of materials and worker movements associated to and from the offsite facility the net savings on transport emissions was 20%.

III. Potential Growth for Offsite Construction

Offsite construction has been growing in its use within housing, education buildings, hotels and student halls of residence during the past 15 years.

More recently new housing using timber frame systems (non-modular) such as closed panels walls, roof cassettes and spandrel panels have become more widespread. Whilst the whole building may not be fully offsite recent construction trends suggest a greater proportion of each building is now adopting an offsite approach.

Fig 4 shows the current trends for new build housing in England and Scotland using different core constructions. Projections for structural core build type expected by 2020 are also shown.

New Build Housing England		
Structure Core	**Current (%)**	**2020 (%)**
Masonry / blockwork	*70*	*60*
Timber systems	*18*	*25*
Other	*12*	*15*

New Build Housing Scotland		
Structure Core	**Current (%)**	**2020 (%)**
Masonry / blockwork	*25*	*15*
Timber systems	*65*	*80*
Other	*10*	*5*

Fig. 4 Current and projected 2020 core constructions of new homes for England and Scotland.

It is anticipated that England and Scotland will increase in utilisation of timber and other forms of construction, which are non-blockwork based.

Whilst Scotland has already high levels of timber construction the silver and gold targets of Section 7: Sustainability building standards will lead designers and architectural technologists to opt for more timber based systems.

Fig 5 shows the relative proportion of new homes utilising offsite construction techniques for parts of the build system and projections for 2020. The most significant step change will be in Scotland due to the predominance of timber based construction systems being more adaptable to offsite designs and methods. One of the drivers for change towards offsite may stem from future City & Regional Deal plans to accelerate low carbon housing provision. These have the potential to introduce framework contracts spanning several years that can harness offsite construction, local and regional supply chains and embed skills support.

England	**2015 (%)**	**2020 (%)**
Offsite	*8*	*25*
Non-Offsite	*92*	*75*

Scotland	**2015 (%)**	**2020 (%)**
Offsite	*40*	*70*
Non-Offsite	*60*	*30*

Fig. 5 Current and future projected use of offsite construction techniques for parts of the build system in new housing for England and Scotland.

New materials such as cross laminated timber (CLT) for use in modular systems and new lightweight steel modular systems are also expected to increase as new manufacturing facilities are opened. Recent advancements on concrete offsite construction systems for housing and new manufacturing plants being operational in 2018 will assist this growth.

IV. Growth of MMC Techniques

Whilst the offsite non-modular and modular markets increase it is anticipated that utilisation of other forms of modern methods of construction (MMC) will also increase. These could include:

- Adapted construction process – a process or product which can deliver reduced waste, saving build time and supporting lean approach [*example: aircrete or concrete whole storey panels replacing normal blockwork coursing*]
- Advanced products/materials – which can increase performance but using the same quantity (or less) of materials during construction, thus providing a reduction on overall material usage and carbon footprint [*example: cellular blockwork providing high compression strength but using 20% less materials*]
- Robust products and systems – which reduce workmanship variances or enhance build performance or reduce waste or avoid secondary measures later in the construction phase [*example: timber frame 'acoustic wall strap' – using 30% less steel, providing double the strength, designed to improve site installation practice and reduce acoustic coupling across the wall*]

Recent advancements in CLT will provide for large element wall, floor and roof panel approaches that can reduce time on site. New multi-function structural connectors, adapted floor system cassettes, integrated pod service units and advanced safety site construction measures also have the potential to increase productivity and shorten build times on site.

V. Discussion

The rise in housing demand via increasing population and reduction in household size is placing considerable pressures on existing housing supply, housing waiting lists and requires advanced construction solutions and shorter construction times. Specific increases in demographic changes both for age groups 'over 55' and 'over 85' years and also the need for more '1 to 2' person households is also shifting the future supply needs and requirements. Specific offsite retirement and care home designs that are designed for this sector and built in their local communities, would be attractive whether to buy or rent. There may also be less financial risk as owners downsize from higher capital assets and also release existing family homes back onto the market.

Skill shortages, particularly in traditional construction skills, due to school leavers choosing other sectors, negative media about the construction sector during the recession and lack of significant upswing in apprenticeships, without more focused accelerated training and education will lead to a skills shortage for some years to come.

Shortages of skilled labour will also place additional inflationary pressures on wages and market churn of labour as competition between companies to employ key site staff intensifies. Potential shortages of EU skilled on-site workers are expected, following the UK's EU referendum 'brexit' result. The traditional construction methods will need to adapt and move towards more multi-skilling, offsite approaches and provide an alternative attractive sector for school leavers to deliver on the quantity of future construction planning in the pipeline. Offsite construction may reduce the on-site labour demands also providing a better and more attractive working environment in the future.

Material shortages in stocks and inflationary pressures on materials (due to demand and supply issues) are already impacting the sector such as for brick and block. Adoption of external wall high insulation render systems and pre-fixed brick slip panels are likely to increase in specification usage.

Offsite construction has the potential to have a more structured control on supply, leaner process and have benefits in relation to reduction in third party supply chain by focusing on B-2-B relationships.

UK government policies, Scottish government policies and private developer needs are moving

more towards supporting the engagement in further offsite construction due to leaner approaches, reducing construction times, resource efficiency, sector skill shortages and carbon and environmental benefits.

The future planning submissions outlined in the Lyons Review[26] and investors behind these projects will shift from 80% housebuilder driven to 65% non-housebuilder driven. The changing funding mechanism for future housing and swing towards private investors, pension funds and various alternative investment models for housing will change the dynamic of market stakeholders, clients, supply reaction and required build times.

Overall build times will need to be shorter due to the market moving towards higher percentage of rental and investors looking for early returns on homes being occupied, similar to the hotel sector date of 'first-occupancy' model.

As government releases land banks and local authorities and housing associations need to address higher waiting lists it is anticipated that larger framework agreements to supply housing may occur. Companies that have the capacity to increase supply via offsite construction approaches are more likely to secure such frameworks and partnerships. However, investment in future offsite manufacturing facilities is primarily stimulated if companies know there is a strategic large scale supply contract framework in place. Without such frameworks and large scale pipeline projects spanning many years there is unlikely to be the paradigm shift needed towards increasing 'infrastructure manufacturing' such as offsite.

The supply of new schools, replacement of existing schools and early years provision over the next two decades also suggests a role for full or partial offsite construction, particularly in the shorter 'window' build times and constrained sites.

Whilst there are existing offsite providers for schools, new offsite systems that can cater for housing, health and education designs may provide an attractive model for some local authorities in delivering multi-function projects for their local needs. Elderly care, retirement homes and assisted living are key areas of growth over the next three decades. Given the UK wide need for such provision the reduction in complexity and added-value offering via an offsite system that can be supplied to anywhere in the UK may be attractive for future investors who will cater for this sector.

The role of the architectural technologist over the next decade will be significant not only in the initial design and delivery of technical solutions but also in the utilization of building information modelling (BIM). Offsite construction through the upfront design and tackling early the technical compatibility issues provides a natural alignment with BIM objectives and functions. The future scope of limited material resources may require the need to embed a future deconstruction solution within future building designs. It is therefore likely that future procurement models may request designs that can provide deconstruction solutions and this may in turn direct designers to adopt greater use of offsite construction.

VI. Conclusion

The growth of offsite construction in the coming decade due to the key drivers of the UK's building infrastructure demands, skills shortages, building performance and sustainability policies has real potential. New skills will be required and site managers will need additional training support as the intensity of logistics is increased and the time factors of delivery schedule and build sequence are reduced. The UK is not unique in relation to the issue of housing and building infrastructure demands. The UN estimates that global population is on a 'medium' trajectory towards 11.2 billion by year 2100 with an expected increase of 4 billion population over the next 85 years. Given the average global household size of 2.8 and the increasing life expectancy and habitat needs, with a 9% increase in household provision above the population increases, suggests over 2.3 billion

homes will be required globally in the next 85 years. As such almost all countries will need to address such issues placing significant pressures on skills, materials resources, land availability and speed of build. Those countries that adapt earliest and initiate national housing programs, through a 'paradigm shift' towards offsite construction are more likely to avoid later global skill shortages, material resource constraints and reduce the impact of inflationary labour and material costs.

Offsite construction can enable better productivity within the UK infrastructure manufacturing and supply chains sector. But it can also provide an export platform, as more countries adopt similar construction, building regulations, performance and sustainability standards.

The role of the architectural technologist will be critical in the delivery of offsite construction and meeting government sustainability policies. In partnership with other construction sector professions they also provide a wider role in addressing the future societal infrastructure needs that could deliver a significant positive legacy in the decades to come.

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