THE EVERETT REVIEW OF BRITAIN'S HOUSING SUSTAINABILITY

Housing that doesn't cost the Earth

The Everett Review was written and researched by Andrew R. Everett.

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ABOUT THE AUTHOR

Andrew Everett has a range of practical and academic experience in the UK residential sector. He began his career as a joiner before working in estate agency, land acquisition for a national 'top three' housebuilder and building surveying. Everett holds a number of awards, qualifications and accreditations in his respective areas of expertise, being a chartered surveyor with a master's degree in building surveying. Andrew's broad range of industry experience provides him with a comprehensive understanding of the sector.

AUTHOR'S NOTE

The following report aims to bring much-needed attention to aspects of the UK residential sector which are under-researched and largely unknown, even amongst many working within the sector. If the recommendations within this review are adopted, I believe the UK can benefit from significant social, environmental and economic benefits while mitigating many of the gravest issues facing our nation.

I hope that you find this review thought provoking and I am grateful, in advance, to all of those who discuss and share it. Doing so will help to expedite the adoption of the recommendations made herein.

Disclaimer

This is an independent review. The views and recommendations stated herein are the author's and not representative of any organisations to which he is affiliated.

ACKNOWLEDGEMENTS

A number of anonymous interviews were undertaken to inform this research. I wish to express my gratitude to all of those involved.

REVIEW STRUCTURE

Introduction

Structure of Proposal

Section 1: *Key and Secondary Issues*

'Key issues' of the housing crisis and climate change are defined, followed by a number of 'secondary issues' related to housing.

Section 2: *Solution*

A solution to the 'key issues' defined in Section 1 is discussed.

Section 3: *Implementation*

The implementation of the solution in Section 2 is mapped-out. The solution is then challenged with the 'secondary issues' defined in Section 1 to ensure that it is comprehensive.

Section 4: *Summary of Proposals*

An overview of the review's recommendations.

Abbreviations and Acronyms

References

INTRODUCTION

The United Kingdom's aims of emitting net zero carbon by 2050 and meeting housing needs are unachievable and counterproductive if current practises continue. In this review these issues are discussed and a solution which enables both goals to be achieved is proposed. A number of secondary issues are also considered to ensure that the proposed solution is comprehensive. The recommendations outlined in this review are achievable and would be productive to sustainability goals.

EXECUTIVE SUMMARY

See Section 4 – Review Summary on page 91.

PARAMETERS

This review focusses on new build homes in the UK. Approaches to reduce carbon emissions in existing homes are varied and complex, with homes typically requiring bespoke approaches depending on their age, type of construction and numerous other factors. By ensuring new builds are as efficient and sustainable as possible, only a finite number of historic homes will require retrofitting and improvement. If new builds are not significantly improved, the number of homes requiring retrofitting at a later date will continue to increase and put yet more pressure on the future generations. These pressures include an increased need for resources, energy and labour.

This report relates specifically to the UK nations of England, Scotland, Wales and Northern Ireland; it does not include Crown Dependencies or British Overseas Territories. Despite this, what we do in the UK affects our overseas territories.

References to the UK planning system are made herein, though planning is not extensively reviewed in this report. UK planning policy was deemed to be a separate issue which can be improved by way of local and national governmental reform. The focus is primarily on residential construction methods and materials, with solutions requiring minimal legislative amendments.

POINTS OF NOTE

Plain English has been used throughout to allow readers to comprehend the review without sector-specific knowledge. Where industry-specific terminology has been used, it is followed by clear definitions. A 'definitions and abbreviations' section is also included at the end of the review.

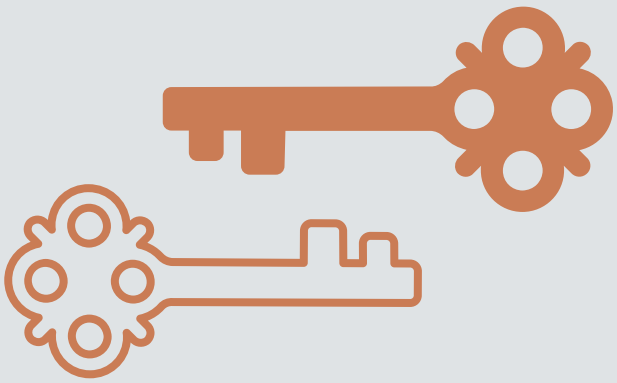
Statistics and estimates on climate change and greenhouse gas (GHG) emissions are cited herein. Given the nature of global warming and our limited knowledge of its effects, it is important to note that these are estimates only. Effects of global warming could be more or less severe than currently predicted.

The UK will be subject to a greater regularity of extreme weather events caused by climate change. It is therefore important to ensure that new builds are constructed to enable comfortable living in our current and future climates.

Should the UK meet its climate aspirations, there is still no certainty that other nations will achieve theirs. It is estimated that the UK emits just 1% of global greenhouse gas emissions.(1) This does not mean that the UK is insignificant in the fight against climate change, although it does demonstrate how dependant we are on other nations' commitment to reducing their emissions. As developing countries industrialise, nations currently producing negligible greenhouse gas emissions may become large-scale polluters. Likewise, nations which are currently on target to reduce their greenhouse gas emissions may have changes in policy, causing them to fall behind on targets. What is crucial is that we hope for the best, yet prepare for the worst. It is the safest course of action for the UK to become as sustainable as possible, in the shortest amount of time possible. If the proposals recommended in this review are adopted, the UK could provide a model for other nations to follow, resulting in a reduction in worldwide emissions.

SECTION 1

KEY AND SECONDARY ISSUES



OVERVIEW

Section 1 is subdivided into 'Key Issues' and 'Secondary Issues'. Key Issues are the housing crisis and climate change, the later focusing specifically on greenhouse gas emissions. Following an overview of both issues in isolation, facts are presented to demonstrate how these issues influence one another. Without proper management and awareness, attempting to solve either one of these issues could intensify the other.

Secondary Issues all relate to housing and as such, must be considered when proposing a comprehensive solution to the key issues. A thorough understanding of these secondary issues ensures that the proposed solution does not meet the needs of the 'Key Issues' while being unachievable because of; or significantly detrimental to, these Secondary Issues.

KEY ISSUES

HOUSING CRISIS

The UK is in the midst of a 'housing crisis' with too few new homes being constructed to meet demand. This has led to increasing house prices, increasing rental costs, overcrowding and fuel poverty, all of which contribute to a lower quality of life for citizens. The average cost of a UK home is now at a record high of £270,000 (September 2021) (2); eight-and-a-half times the average annual salary of full time employees (£31,000) (3). In the past 10 years, house prices have increased by 59% (4) while wages have increased by only 26% (5) over the same period. The proportion of those living in private rented accommodation has also doubled since the year 2000.(4)

It is evident we must build homes in greater numbers in order to meet demands and overcome the housing deficit. By increasing housing supply, demand will decrease and housing will become more affordable. As homes become more affordable, the quality of life for British citizens will improve. A decrease in house prices and rental costs would increase disposable income, allowing residents to invest more into the wider economy, in turn fuelling economic growth.

In 2017 the government published the housing white paper 'Fixing our broken housing market', which acknowledges the long-term failings of successive governments. The government's aim is for 300,000 new homes to be built annually by the mid 2020's. For context, 240,000 new homes were created in the 2018-2019 fiscal year; a 32 year high.(6) Several studies indicate the current target of 300,000 new homes per annum is too low. Research undertaken by Heriot-Watt University concluded that 340,000 new homes should be constructed annually in order to meet demand. Although this higher estimate has not been adopted by the government, it stands to reason that any construction solution created to solve the housing crisis should be scalable in case housing targets are revised.(7)

"*Productivity has changed little in the construction industry in the past 50 years*"
Office for National Statistics.(8)

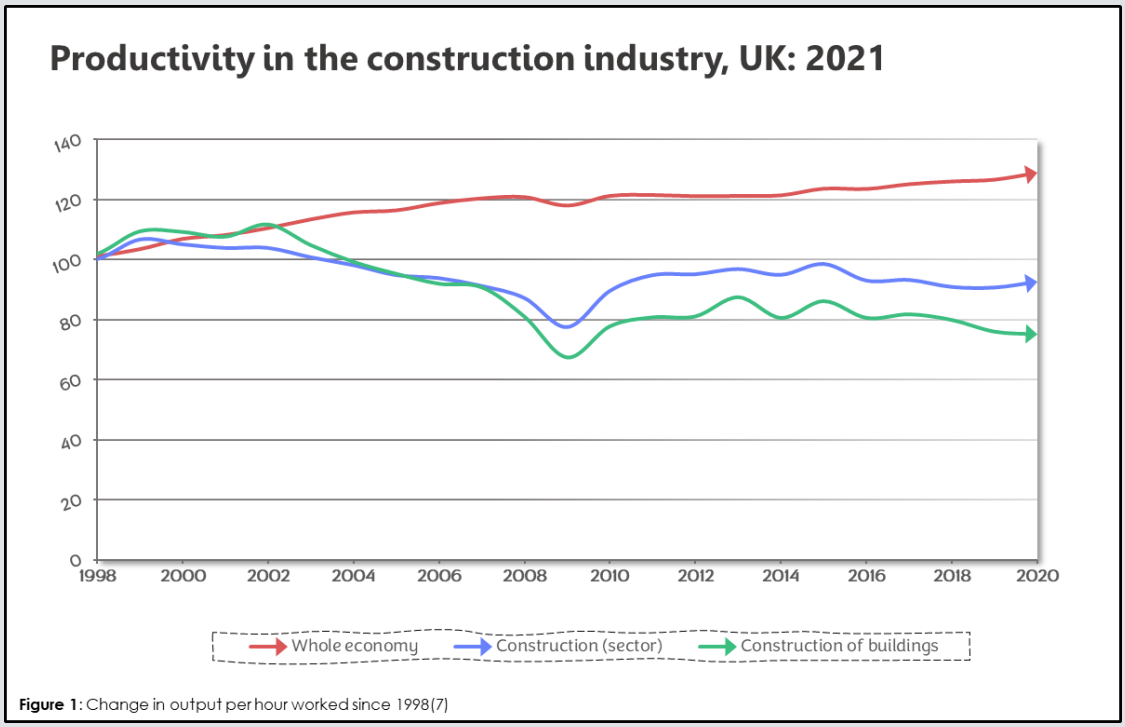


Figure 1: Change in output per hour worked since 1998(7)

Figure 1 shows that productivity per hour worked across the economy of the UK rose by 29% between the years of 1998 and 2020, whereas within the construction sector, it shrank by 8%. As a result, the number of buildings constructed over the same period has decreased by 25%.

The lack of improvement in productivity within the sector is primarily due to the continuation of 'traditional' building methods, which require large volumes of manual labour to construct homes. At present, the UK builds 80% of its homes using 'traditional construction', with an estimated 14% being timber-frame construction.(9) Traditional construction involves housing being constructed with bricks and concrete blocks, with the process largely taking place on-site (although some larger components, such as roof trusses, are constructed in factories).

Traditional construction does have some benefits:

- The UK's residential construction workforce is trained and experienced in this method of construction.
- Traditional construction lends itself relatively to being scaled-down easily should the house market decline.
- It is well-suited to the construction of bespoke homes.
- Traditional construction is often cheaper than alternatives, simply because it is the building norm in the UK, benefitting from established supply chains and economies of scale.

This list of positives does not, however, outweigh the aforementioned evidence that traditional construction is now unfit for purpose. It is clear an alternative method of construction must replace it for housing to meet current needs and the needs of future generations. Traditional construction is labour intensive with almost all manual work being undertaken on-site. It is also more reliant on the weather and the availability of labour. Large quantities of new tradespeople are required to increase construction outputs, and these tradespeople take years to train. Ultimately, due to a combination of the factors above, traditional construction has a maximum output which limits the number of homes which can be built.

MODERN METHODS OF CONSTRUCTION (MMC)

Other sectors, such as the automotive industry, utilise technology and robotics to create high-quality, standardised products with reduced labour requirements. The renowned 'Farmer Review of the UK construction labour model', subtitled *'modernise or die'* and referred to hereafter as the 'Farmer Review', concluded that due to labour shortages, the UK's housing targets cannot be met while traditional construction methods dominate the sector. The Farmer Review proposes an increased use of modern methods of construction (MMC) in order to meet demand. MMC involves a greater proportion of residential construction being undertaken in factories, in a similar fashion to that of many other manufactured products.(10)

The March 2020 budget, titled 'Delivering on our promises to the British People', concurs with the view that new homes must be built at a faster rate and using less labour if the UK is to meet its housing targets (11,12). The Royal Institute of Chartered Surveyors (RICS) also condemned traditional construction as being "*incapable of delivering the volumes of housing needed*".(13)

The Farmer Review also states that too few people are joining the construction workforce to replace those retiring or leaving for other reasons. It estimates that the UK construction workforce may decline by 20-25% over the next 10 years.(14)

Evidence suggests that attempts to increase the number of construction workers as a means of increasing output would also be unsustainable and ineffective.(13) The only viable solution is to construct homes using less labour, which in turn can only be achieved by increasing build efficiency through the use of automated manufacturing techniques and technology. Building new homes in factories (MMC) is already underway in other industrialised nations, and on a negligible scale, in the UK. Despite the UK being a technologically advanced nation in need of mass housing, it is falling behind other nations, such as Japan, which currently builds 15% of new homes using MMC.(13)

There are numerous benefits to MMC:

- Low labour requirements due to improved work efficiency. Efficiencies are a result of numerous factors including reduced weather delays, highly specialised workers and greater use of technology and manufacturing equipment not available to on-site workers
- Low levels of construction waste. Reasons for this are outlined in Secondary Issues.

- Improved build rate as properties' superstructure (the element of the property above ground) can be built in a factory at the same time as the substructure (the below ground elements, such as foundations) are being created on-site. This is in contrast to traditional construction, where construction stages must be undertaken in a linear fashion, with superstructure construction only commencing once substructure elements are completed. Increasing build rates results in reduced build time and costs.
- Weather delays are reduced as a greater proportion of construction is undertaken indoors.
- Enhanced build quality due to use of high-precision manufacturing techniques and a controlled factory environment offering greater supervision of workers and quality control.
- MMC facilities offer a safer, more supervised working environment for employees.
- When operated at a sufficiently large scale, construction costs are reduced when compared with traditional construction, due to decreased build times, waste, labour needs.

Although MMC uptake in the UK is slowly increasing and awareness is growing it has not been adopted on a sufficient scale. There are a number of reasons for this, including a high initial costs and greater risks to organisations. These hurdles are discussed later in the review.

CLIMATE EMERGENCY

Greenhouse gas (GHG) emissions are the primary cause of climate change, and have therefore been deemed a 'key issue' for the purposes of this review. GHGs include water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

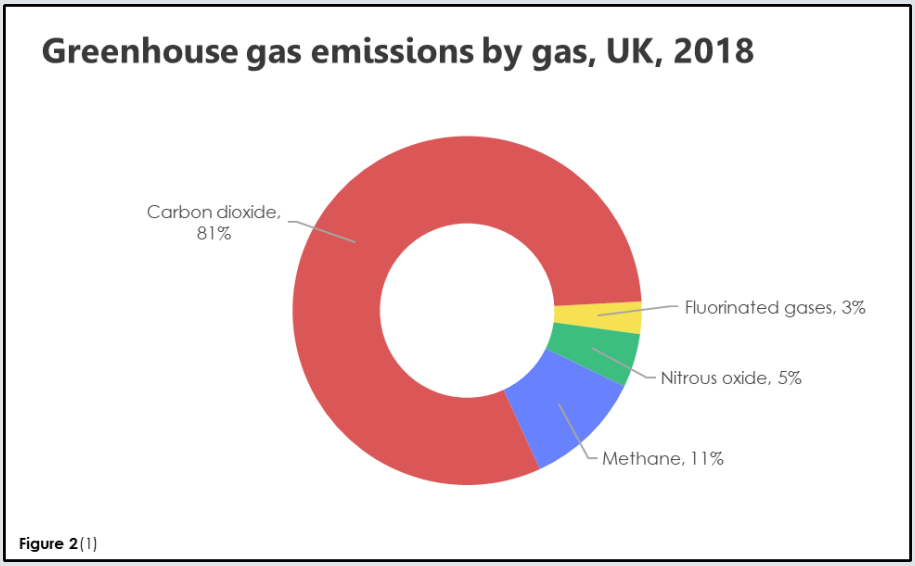


Figure 2(1)

GHGs have varying global warming potential (GWP), meaning some gasses have more potent greenhouse effects than others at identical volumes. Despite CO_2 having the least potent GWP, it poses the greatest risk to global temperatures, due to its high volume of emissions. As a result of this, the UK government has declared a "climate emergency" and has passed legislation that commits to reducing carbon emissions to "net zero by 2050".(15)

The energy used in construction and in lived-in homes represents a huge proportion of the nation's GHG emissions: household energy use accounts for 21% of the UK's GHG emissions alone.(1) In recent years, there have been concerted efforts to raise awareness of GHGs among UK residents in an attempt to reduce emissions. It is crucial, however, to consider the whole lifecycle of our homes including the impact of construction and demolition.

Statistics on GHG emissions during construction and demolition are limited. Data is typically categorised as 'construction' without differentiation between emissions from civil, commercial or residential projects. Despite this, it is common knowledge that the extraction and processing of raw construction materials, such as from quarrying, has huge detrimental effects on the environment. Furthermore, resources and workers are regularly transported to and from construction sites, with excess materials and waste frequently being removed. The production, transportation and disposal of construction material produces large quantities of GHGs, namely carbon dioxide. Concrete alone accounts for 8% of all global CO_2 emissions, and the energy equivalent of a gallon of petrol is used to manufacture every six bricks.(16) The manufacturing process of steel and other common construction materials also results in significant GHG emissions. The use of timber in construction also results in trees being felled which would otherwise be absorbing carbon. A number of environmental issues are associated with deforestation and these are compounded by the UK's low quantity of forested areas. The UK is one of the least densely forested nations in Europe having the second highest net timber import deficit globally, surpassed only by China.(17)

As stated, it is difficult to ascertain what proportion of GHG emissions should be attributed to each stage of a building's life. Research undertaken at the University of Manchester estimated that 90% of GWP arise during the in-use stage, 9% during construction and 1% during the demolition.(18) It should be noted that this review assumed a building lifespan of 50 years; in reality, many homes will be in use far longer than this, thus greatly increasing the percentage of emissions during the in-use stage, heightening the importance of energy efficient homes. As shown in Figure 3 (below), space heating accounts for the greatest proportion of in-use energy consumed and highlights the importance on constructing well-insulated homes.

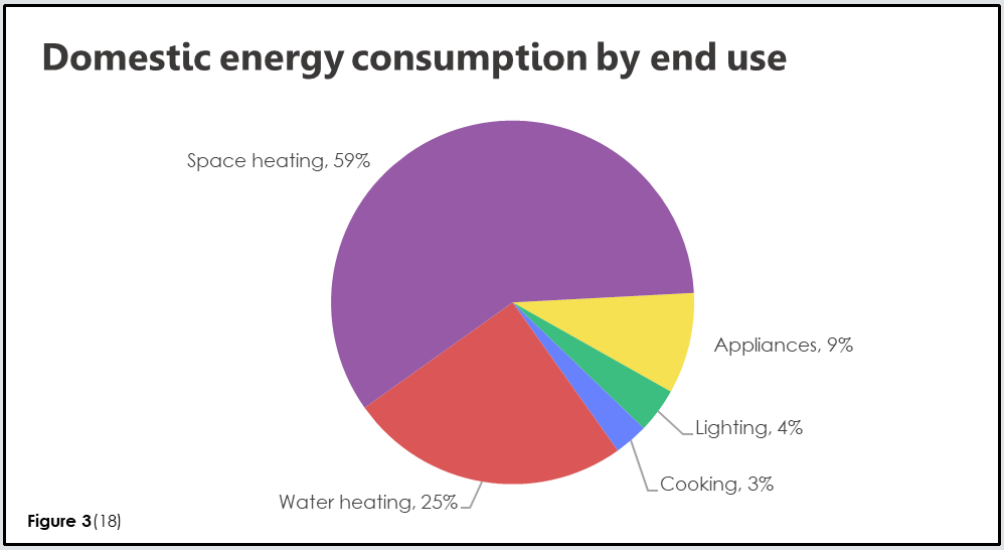


Figure 3(18)

As shown in Figure 3, space heating accounts for the greatest proportion of energy use in UK homes, highlighting the importance on constructing well-insulated homes.

From these findings, it is evident that energy efficient homes must be constructed in high quantities, with a primary focus on reducing in-use energy and emissions from their construction.

KEY ISSUES SUMMARY

It is the consensus opinion that Traditional Methods of Construction (TMC) cannot keep up with the growing demand for housing. The uptake of MMC is required to overcome labour shortages and meet the UK's housing targets. The government is providing grant funding to organisations establishing MMC factories to incentivise uptake.(19)

Although the increased uptake of MMC can help facilitate the UK's housing targets, in its current format it could negatively impact environmental aims. This is because many MMC homes focus only on low labour requirements while utilising large quantities of steel and concrete in their designs, which emit greenhouse gases during their production. Some MMC factories offer more sustainable housing solutions by utilising large volumes of timber in their designs, increasing carbon sequestration. Utilising timber in construction stores carbon for the building's lifetime and is often referred to as a 'carbon bank': approximately 50% of timber is stored carbon.(13) Deforestation however has a significant environmental impact. The UK also has a low availability of timber and a high reliance on timber imports.

Current research focuses on reducing lived-in residential CO_2 emissions while neglecting emissions from the construction phase. There is also a lack of awareness regarding the potential for building materials to capture and store CO_2. This poses a great opportunity to transform housebuilding from a GHG producing industry to one of CO_2 neutrality, should these materials be effectively implemented. It is a short-term approach and squandered opportunity for the UK to move away from traditional construction only to replace it with new methods of construction which do not contribute to the nation's carbon emission targets. MMC homes should, as a minimum, emit less greenhouse gasses in their construction and lifetime than traditionally-built homes. Here is an opportunity for a 'new norm' to replace traditional construction; this new norm must not impede the nation's ability to meet its carbon reduction targets and ultimately should provide the brightest possible future for the nation.

We must build factory-made homes which are sustainable, capture CO_2 in their construction and 'bank' CO_2 for their lifetime. These homes must be built with relatively low levels of labour to provide the quantity of housing the country desperately needs. Our new generation of homes must also have low energy requirements, low-running costs and be comfortable to live in; even when accounting for more extreme weather events as a result of climate change.

SECONDARY ISSUES

OVERVIEW

The following 'Secondary Issues' either significantly affect or are affected by the UK residential sector. These Issues must be considered to ensure that any future UK housing solution is comprehensive, making the most of opportunities and mitigating any areas of concern.

LABOUR SHORTAGES

In the 2018-2019 fiscal year, in the region of 240,000 new homes were created.(6) The government's aim is to build 300,000 new homes by the mid 2020's. A shortage of labour is the key reason why the UK is struggling to meet its housing targets. It is estimated that an aging workforce and a limited number of new starters in the industry will result in a 20-25% decline in the available labour force from 2016 to 2026.(10) This will lead to a *"long-term and inexorable decline"* in the industry.(10) Figure 4 shows the low uptake of younger generations in construction, while Figure 5 shows estimated employment demand for various sectors in the UK.

Figure 4(10)

Figure 4 shows that the number of those joining construction is insufficient to replace current labour and far below that required to increase traditional construction output. It is widely accepted that comments made in the Farmer Review, which highlight an impending labour crisis in the construction industry, are accurate. As 30% of the construction industry are aged 50 and over it, is estimated that 620,000 workers must be recruited into the sector between 2016-2026 in order to maintain current output, and more still to increase it.(10)

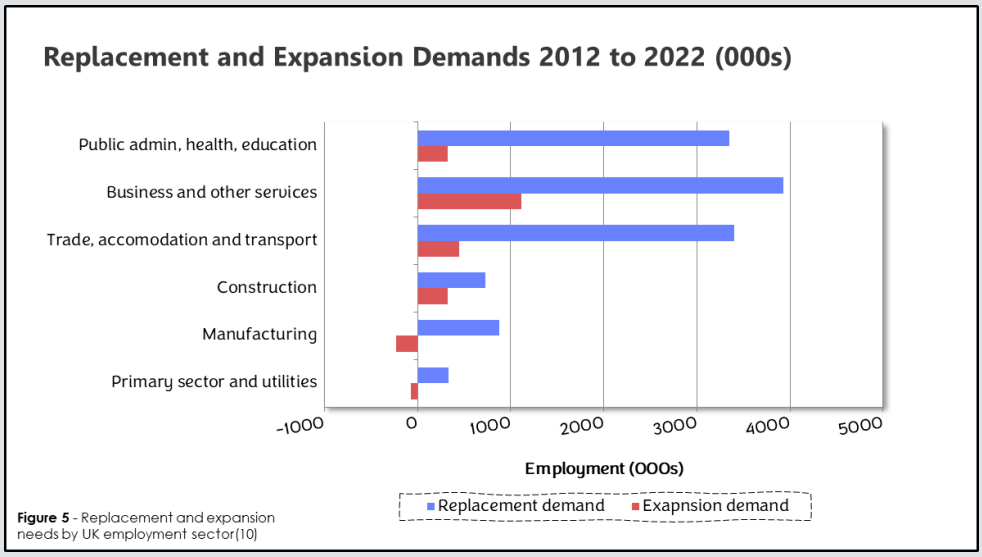


Figure 5 - Replacement and expansion needs by UK employment sector(10)

Young people must be attracted to construction to replace retirees and those leaving the industry. Figure 5 highlights that other sectors however have still greater need of new workers than construction. The attractiveness a career in construction will be considered by prospective employees against the benefits of joining other high demand sectors.

The construction sector is viewed by young people as an unattractive career choice,(20) and the sector is finding it increasingly difficult to attract and retain new workers. The construction industry can be lucrative for many, and is also one of the easiest sectors to enter for those without higher education.(21)

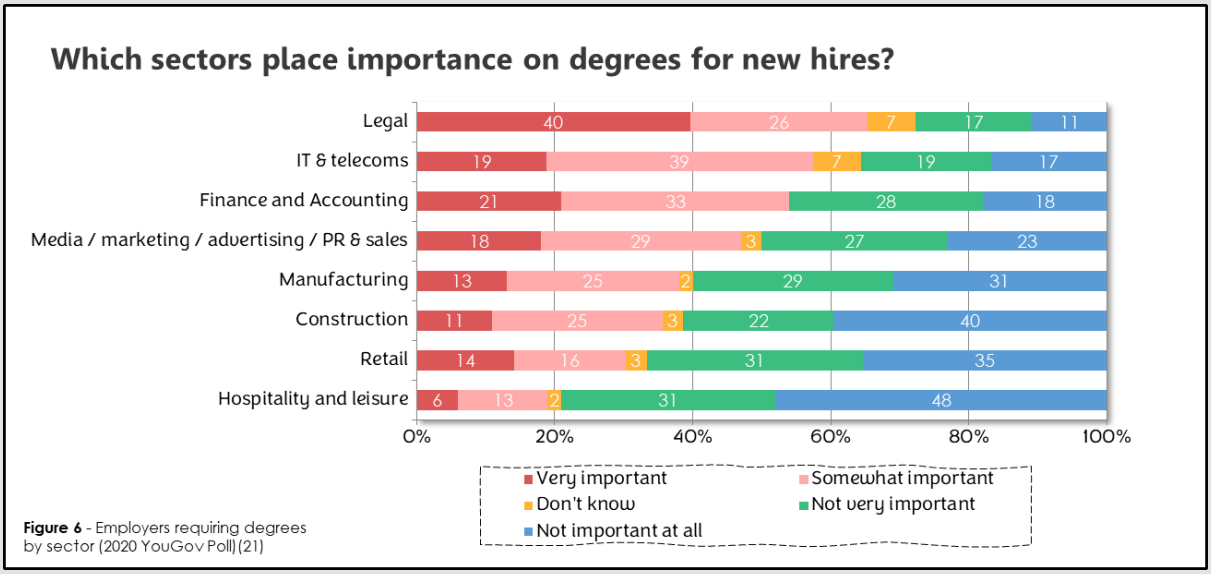


Figure 6 - Employers requiring degrees by sector (2020 YouGov Poll)(21)

A 2015 YouGov poll, shown in Figure 6, reported that despite the demand for labour and ease of entry, only 3% of men aged 18-24 have searched for jobs in construction, dropping to just 1% for women in the same age range. Despite this, 46% of UK residents aged 18-24 acknowledge that construction is important to the UK economy.(22)

Of those questioned (22):

- 45% felt jobs in construction were targeted mainly at men.
- 26% felt employment in construction offers little job security.
- 19% believe that construction is not a desirable industry to work in.

Numerous reports concur with YouGov's findings that the construction sector has a poor image, and struggles to attract women and minority groups. If the labour crisis is not overcome, output will plummet due to an inadequate workforce. Due to high demand, a smaller workforce would also result in higher labour costs, leading to increased build costs and housing prices. These factors will prolong and exacerbate the housing crisis.

The current construction labour shortage can be solved by:

- Introducing wide-spread use of factory-based construction (MMC), therefore reducing the labour requirements.
- Making employment in construction appealing, so that more workers are incentivised to join, and remain in, the sector.

With modern advancements in machinery and automated manufacturing, factory-made homes can be built to a higher standard and at a larger scale than in the past. Unpredictable weather is of little consequence to MMC, therefore offering the most effective solution to the UK's labour shortage issue. Factory-made homes can be built in a variety of methods: some comprise of factory-made walls (known as panels), while others construct entire rooms (known as pods). Panels and pods take only a fraction of the time to construct compared with TMC with panels manufactured under efficient circumstances. Once manufactured, they are transported to construction sites for assembly.

The government has acknowledged the urgent need for factory-built homes, as stated in the housing white paper 'Fixing the broken housing market'.(11) MMC alleviates the issue of labour shortages in the construction industry, due to more efficient manufacturing techniques and a greater use of machinery. Despite the lower labour requirements involved, it is still necessary to attract a large number of new workers to the industry.

Not only is MMC more efficient, requiring less labour for increased output, but MMC tradespeople typically require less training than their traditional counterparts. A large-factory setting means that construction workers undertake a narrower scope of duties compared to traditional tradespeople, with roles comparable to those in other factory or assembly line settings. Utilising specialised workers improves the quality of housing components while reducing the amount of time spent training new staff, leading to increased output.

In the UK, MMC is still in its infancy. It will take time to disseminate information and train a workforce to a sufficient standard. Employees could be sourced from existing MMC companies, existing tradespeople and from a wide range of other industries, such as the manufacturing industry. Many housebuilders employ veterans in construction with specific training programmes already established. MMC builders could similarly look to employ veterans. The workforce could also be bolstered by those who are unemployed or looking to upgrade from low-wage sectors, such as hospitality or retail. Sourcing employees for MMC factory-based construction is discussed further in Sections 2 and 3.

Concerns about the image of the construction industry could also be changed by utilising MMC. By moving away from construction site stereotypes to more professional factory workplaces, women and young people may begin to view the industry as an appealing alternative to other sectors. TMC can be unappealing to young people for several reasons. Companies which use TMC often have construction sites scattered across the UK, meaning many workers must travel long distances or spend weeknights in hotels. This can negatively impact their social and family lives. Many alternative employment opportunities offer flexible working hours, the option to work from home, and time off in lieu. These opportunities have become commonplace following the outbreak of Covid-19. Even when workplaces cannot offer flexible or home working, employees still benefit from reliable commuting, which allows them to pre-plan activities after work. Manual construction work cannot be taken home, combined with static factory locations this provides employees with clear work and home life separation which can be appealing to many. Although MMC is unlikely to offer the same flexibility as computer-orientated roles, MMC does

provide a healthier work-life balance than TMC.

Furthermore, because construction sites are temporary, there is typically limited investment in and limited space for home comforts, which make many workplaces more comfortable for staff. Construction workers often operate from temporary cabins with limited space and facilities for cooking and bathroom breaks. Furthermore, despite their best efforts to keep these facilities clean, given the nature of the work, they can often be unsightly and less appealing than cleaner, larger and better-equipped office workspaces.

MMC factories can provide superior break facilities when compared to on-site facilities, given their permanent nature. Larger numbers of employees would also result in greater investments into such facilities. Working indoors will result in cleaner, more appealing work environments. Construction workers will still be required on-site for tasks such as groundworks and the assembly of the homes, though far fewer workers will be needed than in TMC.

Construction has the highest rate of workplace injuries and fatalities of any UK sector; higher than that of agriculture and manufacturing. The main causes of injuries are falls from height (29%) and being struck by moving vehicles (23%).(23) These two risk areas, as well as many others, can be significantly mitigated by moving the majority of the construction process into safer, better equipped and better controlled factory working environments. Furthermore, environmental risks, such as ice, wind, high temperatures and other hazards caused by the weather are largely removed. In the event that injuries do occur, the fixed location of factory work ensures medically trained staff members are always present and improves the response time of these staff and of ambulances. Temperature controlled factories also contribute to worker wellbeing, reduce the likelihood of injuries and illnesses and make the industry more appealing to would-be construction workers.

As the retirement age in the UK increases, the health of construction workers becomes increasingly important. Workers who suffer from workplace injuries and ailments are less likely to be able to work until retirement age; this negatively impacts their financial security. Fear of injury and resultant financial insecurity is deterring people from considering the construction industry as a long-term career prospect. With MMC, the increased availability of machinery to assist with tasks that commonly cause injury, such as heavy-lifting, will protect the health and future finances of factory employees. Physical labour also leads to fatigue, with those in manual labour roles requiring more sleep, further affecting their social and family lives. Reducing manual activities in MMC factories can also mitigate this drawback of traditional construction.

Improved surveillance in factories will result in mangers having greater control over employees and their work, improving build quality and allowing human resource departments to form closer bonds with technical staff. In turn, this ensures employees feel supported and valued, creating more professional working environments and deterring discrimination which may go unnoticed on building sites. This will improve the image of the industry and increase the appeal of construction to wider demographics, such as women and minority groups, who are currently underrepresented. Building sites have a reputation for being ‘less professional’ than other workplaces, with a higher proportion of outspoken individuals. Closer management in MMC factories can reduce the impact such individuals have on their co-workers, further improving the appeal of the sector.

These improvements over TMC will make employment in MMC a more compelling career option for many UK residents. Demographics which are currently underrepresented in construction work will also be attracted into the sector in far greater numbers than TMC has ever achieved.

MAKING EMPLOYMENT IN CONSTRUCTION APPEALING TO NEW WORKERS

To form an adequately sized workforce construction must be an appealing career choice, particularly for young people who can go on to have long careers in the industry. Young people have a number of choices following their departure from compulsory education: higher education, working in construction or working in another sector: for those in employment this may also include undertaking an apprenticeship.

The UK construction sector has an image problem which must be solved if a sufficient calibre and quantity of workers are to be employed to solve the housing crisis. New entrants to the sector are required even if MMC is implemented.

Key statistics are as follows:

- 1 in 5 young people stated that the sector was undesirable to work in.(22)
- Despite 46% of 18–24-year-olds acknowledging that the construction industry is important to the UK economy only 3% of those in this age range have searched for jobs in the industry, falling to just 1% for women.(22)
- The sectors with the highest proportion of 18–24-year-olds searching for employment are retail (45%), hospitality and leisure (22%), education (18%) and healthcare (16%).(22)

Although it is difficult to quantify the driving factors behind the popularity of retail, hospitality, education and healthcare among young people, some commonalities are evident:

- High degrees of social interaction.
- These roles are typically not desk-based.
- Work in retail, hospitality and leisure have low entry requirements often with little to no qualification requirements and short training periods.
- Education and healthcare offer the security of public sector employment while also providing a moral incentive, whereby employees feel rewarded for providing a service to society.

Construction work does currently offer some benefits which are not catered for in these more popular sectors. Retail, hospitality and healthcare for example typically involve weekend work whereas construction workers primarily only work on weekdays. Furthermore, education and healthcare roles often require employees to have university degrees whereas most construction roles to not have this barrier to entry.

Construction work starting salaries are a key area of concern. Many entry-level construction roles are apprenticeships which are pay less than typical minimum wages. Standard minimum wages in the UK are based upon an individual's age, the wage increasing with the age of the worker in a banding system. For those undertaking an apprenticeship however, as is the case for many construction workers, the minimum apprenticeship wage is just £4.81/hour, the same as the national minimum wage for anyone 18 and under. Minimum apprenticeship wages apply for those:

- aged 18 and under
- aged over 18 and in the first year of their apprenticeship

In contrast 18-20 year olds have a minimum wage of £6.83/hour.(24) Construction apprenticeships typically last 2-3 years although some are longer. Once apprenticeships are completed construction workers can increase their wages significantly. The initial time spent as an apprentice is on incredibly low pay, typically undertaking menial tasks and often with significantly less respect awarded to them by co-workers. For many, this results in an unappealing career choice. Many employers in construction are awarded grant funding in return for taking on apprentices. Apprentice's low minimum wages combined with grant incentives can mean some immoral employers abuse the system, utilising apprentices as cheap labour with minimal training offered in return: apprentices being far cheaper to employ than labourers.

Low apprenticeship wages are for most, insufficient to live off. This is a particular issue for those who are not financially supported by family members, this is a significant problem for those from low income families. Low apprentice wages are also a disincentive for older people to retrain in construction: those over 22 years' old are entitled to a minimum wage of £9.50/hour, almost twice the wage of an apprentices should they choose to retrain.(24) Enduring an apprentice's salary for years is extremely difficult, especially for those with dependent family members. The hardship of attempting to endure low apprentice wages is likely a significant contributing factor why so few are joining the sector and are instead favouring alternatives. Sectors such as retail and hospitality offer higher initial wages for those over 18 and often with the opportunity for overtime work. Work in hospitality also offers further financial reward in the form of tips. Apprenticeships are typically excellent for inducting and training trades people however wages must be increased to compel a sufficient number of workers to join and remain employed in construction.

Grants for training in construction are provided to employers by CITB (the Construction Industry Training Board). Solutions to incentivise new apprentices should include increasing apprenticeship wages for those aged over 18. One means of achieving this would be for employers to pay all first-year apprentices, regardless of their age, the normal minimum wage with the difference in wages between the apprenticeship wage and normal minimum wage claimed back from CITB. This would mean the apprentices aged over 18 benefit from the same wages as those in other sectors while employers are not burdened with this extra cost. Further improvements could be made by amending how grant funding is paid to employers by CITB. At present, grants are typically paid to employers for each year of an apprenticeship or industry-relevant course undertaken. In some instances, a further bonus grant payment is also paid once the course is completed. An alternative would be to provide grant funding to employers based on the performance of apprentices: higher performing apprentices (based on college

grades) would result in higher grant payments to employers. If implemented correctly this could be used to dissuade employers utilising apprentices as cheap labour while incentivising support and learning for apprentices. Undertaking further research and trials to confirm the effectiveness of these proposals would be beneficial prior to large-scale implementation. All incentives should encourage the uptake of apprenticeships and the high performance of apprentices. Success depends upon apprenticeships offering sufficient incentives to both employers and prospective employees while maximising benefits to the sector.

The increased specialism of MMC workers means that the long training periods are significantly reduced and, in many instances, lengthy apprenticeships akin to that of traditional construction will not be required. Staff can therefore work effectively and obtain higher initial wages more quickly than traditional trades.

There is an opportunity to re-market MMC from 'construction work' to a more appealing label, such as 'advanced manufacturing'. It should be noted, however, that manufacturing is also disproportionately appealing to men, with 9% of young men having considered employment in this sector, compared to only 2% of women.(25) Further steps would therefore have to be taken to increase the appeal of MMC across all demographics.

Approximately 57% of those aged 18-34 would rather work for an environmentally sustainable business.(26) If constructing new homes also combats climate change, some of those working in construction will find their work more rewarding, as it is doubly-good for society. To build this green image, marketing and awareness campaigns would have to be aimed at those who are very environmentally conscious. Effective social media advertising may achieve this aim.

Like in the healthcare and education sectors, construction also offers a relatively rare reward to employees in that the fruits of one's labour can be physically seen and appreciated. In healthcare, employees may see a patient's health improve; in education students' performance and confidence can be enhanced. Seeing these positive impacts can be very rewarding. Construction physically changes the environment and can offer a great sense of pride and achievement: this benefit must be effectively advertised to prospective employees.

It is common practice in larger construction companies to have apprentices sent to college or university while working to study to for qualifications such as NVQs or degrees, this is often in the form of day-release once per week during term time. If these opportunities are offered to those working at MMC factories this would incentivise those seeking higher education to work in construction as they would benefit from the opportunity to obtain qualifications without university costs while simultaneously gaining work experience, earning a salary and having long-term employment. Raising awareness of this route to higher education would be beneficial to entice new workers to the industry. In 2019, 40% of all 18-year-old school leavers in England applied for university,(27) encouraging even a small percentage of these to obtain a degree while working in construction would result in worker shortages being mitigated in a short period of time. Although every aspect of the university experience cannot be combatted by this approach, it would improve the construction industry's talent pool and alleviate worker shortages.

TMC involves an early start to the working day, manual labour and typically a workforce made up largely of older men (as shown in Figure 4). Many older people, particularly in construction, can be unsympathetic to needs of young people

as they transition from classroom education to practical work. The industry currently has an underlying 'toughen up' ethos, which is stereotypical of male-dominated workplaces. Although this verdict is anecdotal, it is arguably supported by the rate of suicides in the construction industry, which are higher than any other sector in the UK. Men working in construction are 3-times more likely to commit suicide than the national average.(28) The more comfortable MMC work environment will help to smooth the transition from classroom to workplace, as opposed to the harsh conditions of traditional construction sites. There are likely other factors causing increased suicide rates in the sector including long working days due as a result of long commutes and working away from home involved in TMC, both factors being largely overcome by MMC.

Further proposals are outlined in Section 3 of this review as to how the industry can be made more appealing to young people.

SUMMARY

Factory-based MMC can combat worker shortages by building homes more efficiently, with less labour and to higher quality standards. The improved working environment offered by MMC will entice more workers into the construction sector, further mitigating worker shortages. The improved working environment will also lead to improvements in staff retention. Training times will be reduced, due to more specialist roles and the greater use of machinery and technology when compared with TMC.

The reasons why so few young people are entering the construction industry are difficult to quantify, and a degree of conjecture is required. Evidence suggests that MMC will prove more appealing to young people than TMC, with many existing issues being overcome or mitigated. If marketed correctly, MMC can also be presented as a cutting edge form of manufacturing, distancing its image and reputation from that of traditional construction. Diverse and technological career paths will also encourage staff to join and remain in the MMC industry.

HOUSEBUILDERS

The 2017 UK housing white paper 'Fixing our broken housing market' deemed that the second-most significant cause of the housing crisis, after planning inefficiencies, is that the "*the pace of development is too slow*".(11)

From Figure 1 (p11), in can be observed that the output per hours worked for the construction of buildings in the UK has decreased by 25% from 1997 to 2020; in the same timeframe, the whole economy's productivity has increased by 29%.

Traditional construction involves the use of significant on-site labour working with environmentally-unfriendly components, such as bricks, concrete blocks and cement. Approximately 70% of new homes are built using TMC, with only 14% utilising timber-frame construction.(9) The UK housebuilding sector is currently dominated by large volume housebuilders; many medium and small businesses having ceased trading following with 2008 recession. Currently Britain's ten largest housebuilding firms build around 60% of new private homes.(11) Housebuilding has

changed relatively little in the past 100 years, with a continued reliance on labour to generate output. This stagnation is at least partially caused by a lack of competition in the sector. Increased uptake of MMC will drive traditional housebuilders to adapt to a modernising housing market by applying competitive pressure.

The low productivity of existing housebuilders is the result of low innovation. The technology exists to improve construction efficiency and quality, however existing housebuilders have not adopted these methods. The cause of this reluctance is the risk-averse nature of housebuilding firms. This risk-aversity stems from several notable causes

1 - CASH-FLOW RISKS

Housebuilders and construction as a whole is a high cashflow risk sector. Housebuilders expend huge sums of money upfront to fund their developments, with major costs required for: land acquisition, planning, land remediation, site preparation, groundworks, infrastructure (creating roads, drainage, levelling ground, etc.) and housing build costs. Many of these costs are incurred before the first property is sold and any returns are made. For large sites, it can take years to sell enough homes for the development to break even: during this time, developers are exposed to significant financial risk. If the housing market declines during construction or before sales can be made, house prices can decrease and sales rates can slow, reducing or completely eroding profits. These risks were highlighted following the 2008 recession, when even large, well-funded housebuilders faced significant financial hardship.

Even outside of periods of recession, construction businesses are not safe from the danger of cashflow issues. This was evidenced by the collapse of Carillion in 2018, which sent shockwaves through the industry and served as a stark reminder to the sector of the importance of effective cashflow management. New innovations which increase 'front-loaded expenditure' (i.e. money invested at an early stage in a project long before returns are made and causing high cashflow risk) and increase the risk of cash-flow issues are typically viewed as an unnecessary risk. For example, innovation in MMC would require substantial funding to create factories, purchase machinery and hire and train the appropriate staff, Should the market decline after this significant outlay of funds, it could have severe implications for even the largest and best-funded of housebuilders.

It can take years for MMC housebuilders to become profitable. Ilke Homes Ltd. made a loss of £41M in the 2020-2021 fiscal year; a £9M increase on the £32m loss in the previous year. This was despite revenue increasing by more than double, from £12.7m to £27.5m in the same timeframe.(29) Although this loss is partly due to the COVID-19 pandemic and the company being in its infancy, this highlights the financial risk of housebuilders investing in innovative housebuilding methods. Although modular housebuilders will prevail in the long-term, deep pockets, fortitude and unwavering perseverance will be required. Given their aversion to risk and innovation, these traits are not common among traditional housebuilders.

2 - IF IT ISN'T BROKEN…

The common saying *"if it isn't broken, don't fix it"* is applicable to many situations. In spite of the housing white paper titled *"Fixing the broken housing market"*, many highly profitable housebuilders do exist; from their perspective, their businesses are not broken and do not need fixing. To the contrary, many in the public and the government think housebuilders are failing to deliver the quantity of new homes required.

Housebuilders, such as Barratt Homes, Persimmon Homes and Taylor Wimpey, are regular placeholders on the FTSE 100. These businesses are highly unlikely to change from their proven business strategies, which have seen them thrive during times of high market activity and survive through recessions. From the perspective of existing housebuilders, if it isn't broken, don't fix it…

3 - HOUSEBUILDER OWNERSHIP

An estimated 59% of UK homes are built by volume housebuilders; companies that build over 2,000 homes per year.(11) Of these, many are owned by shareholders and listed on the London Stock Exchange. Housebuilding is typically seen as a 'safe bet' for investors, with house prices going "one way" (up) in the long-term. The expression "as safe as houses" is common in British English, demonstrating the public's long-standing faith in house prices, which-on average increase year-on-year.

These views are well-founded, as the UK's housing needs have failed to be met for decades, leading to increasing demand and house prices. It is logical that those investing in volume housebuilders have invested for the reliability of their returns, akin to that of any 'safe bet'. Should a housebuilder deviate from this typical, low-risk course of action, their investors may sell their shares to invest in a company which is aligned to their safe investment requirements. There is therefore little incentive for existing housebuilders to take what they regard as unnecessary business risks, like investing in MMC.

4 - GOVERNMENT RELUCTANCE TO FORCE CHANGE

Although the government is making efforts to diversify the housebuilding sector and offer financial assistance to new housebuilders, including MMC start-ups, they are not in a position to impose significant changes to existing housebuilders. Any legislative changes to existing housebuilders could have a negative impact on the housing crisis.

Changes take time to implement, particularly throughout large-scale, national businesses. Should changes in practice become a legal requirement, productivity may be further reduced while housebuilders transition to new ways of working. For this reason, the UK government is unlikely to impose significant legislative change on existing housebuilders, in order to maintain housing supply and not risk lowering it further. The severity of the housing crisis is also a longstanding political issue. Any exacerbation of the crisis by the governing party will upset voters; a fact which politicians are doubtlessly well aware of.

5 - START-UP COSTS

For the aforementioned reasons, it is improbable that existing, large-scale housebuilders are likely candidates for adopting MMC. There is therefore the question of new start-up businesses, and their potential to combat the housing shortage. The government is offering assistance to new housebuilders in an attempt to diversity the housing industry. Even with this assistance, large private investments are required to produce MMC housing on a competitive scale. Other issues, such as logistics, must also be overcome: such issues are complex and take time to implement. The logical course of action for any new or expanding MMC housebuilder is to follow a similar course of action to that of large-scale housebuilders. That is, to utilise traditional construction; this has the lowest risk of cash-flow issues and can be scaled up and down with relative ease.

In order for developers to become established and build a large number of MMC homes, they would need an established supply of land for development, reliable factory-output and predictable cost returns. In other words, they would need to own land and have planning permission, so that they can start selling homes as quickly as possible to begin paying off their considerable debts. These debts would include the overhead costs of traditional housebuilders in addition to the costs incurred by MMC factory set-up. Significant private investment and expertise will be required to manage the financial undertaking. In short, new entrants to the housebuilding market cannot afford to innovate. So long as this is the case, MMC factories will not be invested in on a large scale, and the housing crisis will continue.

The major MMC factories created in the UK thus far are funded by other large businesses, such as Legal & General and BoKlok (part-owned by Ikea and the Swedish construction firm Skanska). Many MMC factories in the UK are also acting only in the capacity of a contractor, making houses which are sold to developers. These businesses are therefore reliant on developer's purchase orders. Relying on developers, instead of developing land themselves, adds another middle-man to the housebuilding process, causing build costs and house prices to increase. Conversely, few developers are eager to rely on external companies to provide their housing. In such a scenario, the quality of their homes, and therefore their reputation, is reliant on the MMC factory contractor. Housebuilder's also risk losing their long-established construction expertise, leaving them vulnerable should the MMC contractor go out of business or try to exploit the developer's reliance on them by increasing their production prices.

For new, more productive housebuilding methods to take hold, reliance cannot be placed on existing large-scale housebuilders, MMC factories operating solely as contractors or new start-ups which lack the necessary funding to succeed. For new start-ups to effectively satisfy national housing needs, they must have sufficient land, supply chains and expertise to undertake such a large endeavour. Regardless of their product, factories are only profitable when large, reliable orders are placed: housing is no different. High output and demand is what lowers material and production costs; if these criteria are not met, MMC factories cannot function optimally and housing will remain unaffordable. The above points significantly limit the scenarios in which start-ups can pioneer and produce large quantities of eco-friendly housing using MMC.

Established housebuilders have vast resources at their disposal. Incentivising

these businesses to transition to the mass production of eco-friendly MMC homes could rapidly solve the nation's housing crisis while mitigating environmental issues. This could be achieved by introducing a threat to their market dominance, to which they must adapt. Such a competitor could also establish supply chains and 'de-risk' new construction methods for other businesses to easily and willingly replicate.

This has already occurred in other industries, such as in the estate agency sector. The estate agency market was historically monopolised by 'high-street' estate agents, until the rise of 'online' estate agents. The expansion of online estate agents has not led to the demise of high-street estate agents, as many predicted; approximately 92% of homes are still being sold by high-street agents.(30) On first inspection of this statistic, it would appear that online estate agents have failed, but this is not the whole truth. Although high-street agents have not been supplanted by online agencies, this new business model has forced existing high-street agents to adapt their business practises. High-street agents are now commonly seen working more flexible hours, utilising technology to a greater extent and utilising other innovations to combat the threat online estate agents pose to their dominance. A similar approach could be implemented in construction to accelerate the rate of change in the UK housing market. A new, eco-friendly MMC developer, which pushes existing housebuilders in the direction of national interests, would bring about positive, fast-paced change to the industry. For this to occur, this new enterprise must pose a significant market threat, building homes more quickly, more cheaply and to higher build quality than established competitors. All of these are achievable if MMC is implemented correctly, however some challenges would be faced. These challenges include obtaining a sufficient land bank, obtaining funding and ensuring that the organisation's goals are aligned with national aspirations. Further details on how this could be achieved are detailed in Section 3 of this review.

While it would be ideal for this hypothetical, market-disrupting organisation to be successful in its own right, its primary objective would be to incentivise change in well-established housebuilders. In this way, the sector can be redirected to benefit national interests while utilising the funding and expertise of established private sector organisations to achieve national aims quickly and effectively.

LAND COMPETITION

The market for development land is extremely competitive throughout much of the UK. Only in locations where house prices and sales rates are very low is competition non-existent. In these locations development is either unviable or too great of a financial risk for developers. Development land is often sold by land agents or local councils. Sellers typically receive offers of purchase in the form of informal tenders, which are more commonly known as 'sealed bids'. Bidders make 'blind' offers, with no knowledge of other bidder's offers. They are therefore incentivised to offer as much as they can afford to win bids and purchase land.

Many companies increase business targets year-on-year, with housebuilders being no exception. This appetite to build more homes and generate more profit drives further land competition. In order to achieve their required output, housebuilders do on occasion reduce their profit margins to below what is typical in the market in order to win more bids, therefore

driving demand for land and land prices even higher.

If a developer's housing output fluctuates excessively significant issues can arise within their workforce. Fluctuating housing delivery results in intermittent periods of redundancy and rehiring that coincide with the company's workload. This scenario can lead to increased costs of labour, inefficient construction and low build quality. Some companies use a large quantity of indirectly employed sub-contractors to cope with varying demand, however this is more expensive than hiring directly for the equivalent number of hours worked. As with any business, reliability, consistency and predictability are key to commercial success. As housebuilders attempt to keep their output consistent, even large plots of development land - with capacity for several hundred new homes - regularly see the number of bidders in double figures.

In order to understand land acquisition, it is important to understand how land is valued. Development land is typically valued using a 'residual' valuation. First, the gross development value (GDV) is estimated: this is the expected value of the development should it be completed. Secondly, all costs of creating the development are subtracted from the GDV, including costs associated with construction, financing, sales, advertising, planning and the developer's profits. The sum of money left over (the residue, hence the name residual valuation) is the amount developers will bid for the land. This method of calculating land value is shown below in Figure 7.

Figure 7 - Overview of residual land valuation method (used for the valuation of development land).

Gross Development Value (GDV) **-** **Total Development Costs (including profit)** **=** **Land Value**

Land acquisition is highly competitive and developers are incentivised to create the highest land offer possible in order to win the bid and secure the land purchase. Developers often increase the land value by fine-tuning and scrutinising costs at each stage of the appraisal process. An increase in land value can be achieved by increasing the anticipated GDV, decreasing development costs and/or decreasing the developer's profit margins. Each of these methods are discussed below:

Increasing the GDV – This can be achieved by creating a more efficient housing scheme. Typically, this means that more houses are proposed on the same plot of land, to generate greater revenue from a larger number of homebuyers. It should be noted however, that local authorities review planning applications and can refuse to grant planning permission for developments which do not meet their requirements, which can include development plans with overly-dense housing. Alternatively, housebuilders can increase sales revenues by charging more for the sale of their homes. It should be noted that this option does involve some estimation of house prices. If a developer overestimates how much their homes are worth, it can result in financial losses. To avoid this, developers typically value their homes as optimistically as possible without being reckless.

Decreasing development costs – A wide range of costs are associated with this appraisal stage. Some fees, such as planning costs, may be relatively fixed, while other costs can be fine-tuned by developers. Adjustable development costs include reductions in build costs or the faster delivery of a development, therefore reducing interest on development loan payments.

Developer's profits – Large developers typically have a number of regional offices operating with high degrees of autonomy. These regional offices however have certain parameters set by their corporate head office, such parameters include minimum profit margins for each site acquired. These minimum profit margins can typically only be reduced on a site-by-site basis with corporate approval. Developers may reduce their profit margins to purchase sites for several reasons such as: to maintain housing output, achieve business housing targets, secure land adjacent to existing or future developments (therefore enabling the continuation of construction) or to break into new target areas.

Developers typically aim to utilise a combination of the above methods to maximise land value and therefore secure land acquisitions.

Ultimately, the main benefactor of high land demand is the land owners. In order to reduce house prices, the purchase price of land must decrease. This could be achieved by several means, such as:

Increasing land supply. If more land is designated for development, competition for land between housebuilders will decrease, resulting in lower bids and more affordable homes.

- Increasing the cost of home construction (such as by using legislation to ensure that all new homes have solar panels or other such additions). This would result in additional build costs while adding little to property values. As per the residual land formula shown in Figure 7 this will reduce land values. This would only succeed if made mandatory, therefore avoiding the temptation of housebuilders to remove these additional costs in order to undercut their competitors and win more land bids.
- Utilising direct government authority to ensure large quantities of land are made available for development. For example, compulsory land purchases have been utilised in previous decades to enable the construction of large numbers of local authority homes. Compulsory land purchases involve a government organisation acquiring land from an owner who cannot legally refuse the sale. The Compulsory Purchase Act 1965 ensures that land owners are compensated for their land.
- Compulsory purchases are commonplace to ensure that infrastructure projects, such new roads, can be completed. For many large development sites to be acquired, private developers must liaise with several land owners, this takes time and can be unsuccessful. The use of efficient compulsory land purchases could see large, complex sites, owned by multiple individuals, redeveloped more easily. Although greater government involvement could increase land supply, the efficacy and crucially the ethics of any proposals must be carefully considered.

WASTE

Waste from the construction industry comes in two main forms: construction waste and demolition waste. Collectively, these account for 24% of the UK's annual waste; the single largest source of waste in the country. For each inhabitant in the UK, six tonnes of building materials are wasted every year.(16)

"Accurately quantifying construction and demolition waste is challenging and whilst the absolute tonnage figures are subject to a relatively high level of uncertainty"

DEFRA (Department for Environment, Food and Rural Affairs, 2021)*(31)*

Waste is produced at several stages during the construction of residential homes. Firstly, waste is produced with the extraction of raw construction materials, such as clay, lime and silica. Further waste is then generated as these raw materials are manufactured into construction products, such as bricks, cement and concrete, and again as buildings are constructed. Finally, further waste is generated as buildings are demolished at the end of their life. Although the recycling of construction waste is preferable to its disposal in landfills, it can be expensive and inefficient. Waste should therefore be minimised by good design where possible.

In 2018, an estimated 68 million tonnes of waste was attributed to construction and demolition; though this does not include waste associated with the extraction and processing of raw construction materials.(31) It is estimated that an additional 51 million tonnes of waste can be attributed to the extraction of raw materials each year in the UK. Waste from the processing of raw materials into construction products contributes to England's annual industrial waste total of 10 million tonnes, though the sector's precise contributions are unknown.(32)

Reducing waste from construction and demolition has several benefits:

- Reduced greenhouse gas emissions (from extracting, manufacturing and transporting materials)
- Reduced landfill usage.
- Reduced waste disposal costs.

Firstly, waste could be reduced by utilising biodegradable building materials. Timber and other natural materials naturally biodegrade, unlike many man-made materials, such as bricks, which create a waste legacy. Materials which biodegrade release stored carbon into the atmosphere although this can be mitigated in the long term by harvesting and replanting.

The quantity of materials purchased for each build can also be reduced. As labour costs in construction are high, it is typical for construction sites to order surplus materials to allow for 'offcuts' (pieces of materials which are cut from larger ones, and which are subsequently too small to be usable) and to ensure that tradespeople are not waiting on materials to arrive; the cost of surplus materials is cheaper than having tradespeople unable to work due to material shortages. Construction materials, if not stored correctly, can also be damaged by the weather and human error. Besides the practicalities of surplus materials in TMC, it is impractical to calculate the exact quantities needed for any given build. This is because traditional

construction practices require materials to be cut to size and fitted on site in a linear fashion. It is typical in traditional construction to over-order materials by 10% of the estimated requirements.

Inefficient waste removal is another issue. On large development sites, different skips are used for common waste materials, allowing for the separation of plasterboard and timber from non-recyclable waste. Waste is often placed into incorrect skips, resulting in 'cross-contamination', whereby entire skip-loads, recyclable materials included, are taken to landfills. This is exasperated by a high use of subcontracted labour on UK building sites: subcontracted tradespeople are typically paid fixed sums for each project undertaken, as opposed to hourly rates. This incentivises workers to complete tasks quickly so they can move on to the next for further pay. Resultantly, time spent reducing and correctly disposing of waste is disincentivized. Due to limited space on building sites, only a small number of skips are often supplied, meaning there cannot always be a dedicated recycling skip on-site. A large volume of waste must therefore be sorted off-site which is time-consuming and therefore more expensive. Difficulties involved in separating mixed construction materials also means that less waste is recycled, and greater quantities are destined for landfill.

Many of these issues can be solved by using more biodegradable materials, and by constructing homes in factories using MMC. This would prevent materials from being damaged by the weather. Offcut materials can be more easily reused, particularly if similar homes, which utilise the same building materials, are manufactured *en masse*. A greater degree of waste separation can also be employed in factory environments, as space will be sufficient to house numerous skips Furthermore, due to the static location of MMC factories, more regimented waste practices can be implemented. Ultimately, these practices will reduce waste and ensure that a larger quantity of waste is recycled. The reduction in waste will have environmental benefits, while simultaneously reducing build costs as fewer materials are required.

We must also consider that a large proportion of the homes that we build today will become outdated in the future or be situated on land which will be redeveloped. When this time comes, and today's homes are demolished, they will create waste for our decedents to inherit. We must be more conscious than previous generations when considering the waste legacy we leave behind.

Assessments of the environmental impact of housing in the UK estimate that homes built today will have lifespans of 50–100-years.(18) This figure is drastically too low: pre-fabricated homes built immediately after WWII (late 1940's) were designed to last for 10 years. Despite this, an estimated 1,000-2,000 are still occupied to this day; 60 years after their envisaged demolition date.(33) A vast number of inter-war homes are also fast-approaching their centennials, and over one-fifth of all current housing is over 100-years old.(34) As the quality of housebuilding improves, it can be expected that modern newly built homes will be lived in for far longer than many homes currently occupied today. It is likely that the majority of homes built today will be in use for over two-hundred years. We must, therefore, consider the needs of our descendants and 'future-proof' any new homes.

Regularly retrofitting homes is more costly in time and labour than building high-quality homes from the outset. We must ensure that new builds do not require significant retrofitting, as we may not have the necessary labour for this large-scale undertaking in the future. Retrofitted installations can also be less effective than

those present in high quality new builds. The difference in quality between pre-installed insulation and retrofitted cavity wall insulation is a good example of this.

Crucially, we must not leave a legacy for future generations similar to that of asbestos. We must ensure that all materials used to construct homes today will be of use to our descendants in 200 years' time, or at least that they will not cause massive volumes of long-term waste. It is therefore the safest course of action to utilise natural, biodegradable building materials in our homes. Timber for example can be recycled, used as biofuel or in a worst-case scenario, left to biodegrade. Timber also has a low carbon footprint, with the benefit of storing CO_2 and acting as a 'carbon bank' throughout a building's lifetime. Bricks and concrete are difficult and time consuming to recycle, and the usefulness of their waste products is limited. We have no certainty that concrete, bricks and other commonplace building materials will be of any use to our descendants. Leaving our descendants to dispose of these materials would unfairly hinder future generations.

MATERIAL SHORTAGES AND SUPPLY CHAIN

The UK consumes huge quantities of construction materials, with demands set to increase substantially if the government's aim of building 300,000 new homes per year is to be achieved by the mid-2020's. Sufficient materials must be available to enable this increase in housing output. Otherwise, building material shortages can lead to construction delays and increased construction costs, which in turn increase the price of new builds. This was seen in 2021, where construction material prices rose by 22% over a 12-month period, increasing the prices of homes by 12%. (4,35)

Although demand for housing has, on average, been high in recent decades, it does fluctuate, largely as a result of economic conditions. Some construction materials are more scalable than others to meet fluctuating demand. An example of poor adaptability occurred after the closure and reduced output of brick manufacturers following the 2008 recession. As the housing market began a resurgence following the recession, the demand for bricks also increased; brick manufacturers, however, were unable to reopen and increase output in the timeframe required by the market, leading to brick shortages. In an ideal scenario, manufacturers would be able to be scale production to match demand, with little to no friction.

Issues with imported goods and materials have also occurred as a result of Covid, and to a lesser extent, as a result of Brexit. Eventually, another pandemic or political divide will affect the UK or countries supplying the UK, impacting imports. These occurrences will become more likely as a result of the increasing global population, loss of land due to climate change and the subsequent increase in population density. It is therefore the safest course of action for the UK to utilise domestically manufactured materials, where supply chains are less likely to be affected by environmental and political factors. This would mitigate construction delays while reducing the risk of construction costs and house prices rising abruptly. Furthermore, utilising domestically manufactured materials will reduce CO_2 emissions from transportation, reduce road traffic and provide additional jobs to UK residents. Ideally, UK-sourced building materials should be low cost and renewable; or at least so plentiful that supply is a non-issue.

WATER

Abundant water supplies are essential for household activities and for the construction of our homes. To date, the average UK resident has had a liberal attitude towards water consumption, despite a growing population and climate crisis. Until these issues are solved, water scarcity is likely to become a more common occurrence in the UK and around the globe. As a major consumer of water, our homes should be a key target for water reduction, reclamation and reuse.

The head of the Environment Agency, Sir James Bevan, stated that the UK can expect to be in the "jaws of death" by 2040, whereby unless drastic action is taken, we will have insufficient water to meet our needs.(36) He suggests this shortage will be caused by a growing population and the reduced availability of water. The full effect of climate change on water availability is unknown, however it is evident that its availability will decrease: much of Europe suffered extreme droughts in August of 2022, following an unprecedented heatwave in the previous month.(37)

England and Wales consume approximately 14 billion litres of water every day. The Environment Agency estimates that England will require an additional 3.6 billion litres per day by 2050 to avoid shortages(38). The UK has not been constrained by water shortages in the way that many other nations have, and this has led to liberal water usage by its residents. It is advised that UK residents should work towards reducing their water usage from an average of 140 litres per person, per day to 100-110 litres.(36,38) The World Health Organization's (WHO) advises that a minimum of 50-100 litres of water are required per person, per day to ensure that basic needs are met and that health concerns do not arise.(39)

Changing the habits of individuals can be incredibly difficult. As such, decreasing household water consumption is more likely to be achieved by way of building design. Examples of water-efficient design include dual-flush toilets, water-efficient shower heads and water reclamation measures, such as rainwater and greywater harvesting. Rainwater harvesting is the collection and storage of rainwater for purposes other than drinking. Greywater harvesting is the collection of water from sinks, showers, baths and appliances (washing machines, dishwashers, etc.), for use in toilet cisterns. Retrofitting these measures can be cost-prohibitive. Ultimately, in order for significant progress to be made, new homes must be designed to incorporate these features from the outset. It is estimated that the cost of building new homes with features that result in the recommended average daily consumption of 100-110 litres per person, per day would cause an increase in build costs of less than £10 per home.(40)

In addition to domestic water consumption, vast quantities of water are also used when manufacturing construction materials. This includes concrete, which is typically comprised of 15-20% water.(41) By moving away from water-hungry materials, water shortages can be mitigated and reliable construction can be ensured.

FUEL POVERTY AND HEALTH

A household is considered to be fuel poor if: they have required fuel costs that are above average (the national median level); were they to spend that amount, they would be left with a residual income below the official poverty line.

As of 2018, 10% of UK households were in fuel poverty. The average fuel-poor household requires a reduction of £334 from their annual energy bills to be raised out of fuel poverty; this value is known as the 'fuel poverty gap'. The occupants of energy inefficient buildings are more likely to live in fuel poverty, due primarily to expenses associated with heating. Energy performance certificates (EPCs) are typically used to assess the energy efficiency of homes. EPCs rate homes in bands, ranging from 'A'-'G'. Band 'A' homes are the most energy efficient through to band 'G' homes, which are the least energy efficient. A high proportion (28%) of all Band G households are fuel poor with these households having an average fuel poverty gap of £1,339.(42,43)

Housing is used by many as not only a home, but increasingly as a place of study and work. As technology continues to improve many jobs are changing. Our aging population will also result in a greater number of people spending time at home. In 2016, 11.8 million (18% of UK residents) were aged 65 and over; by 2041, this will rise to 20.4 million (26% of UK residents).(44) If a large portion of the elderly population continues to reside in poorly insulated housing, such as housing which is excessively cold or warm, social healthcare services will not be able to keep up with the resultant illnesses. Those over 60 years of age account for 15% of all those in fuel poverty, and this can be expected to rise as the number and percentage of over 60's increases.(42) It is clear that in order to reduce fuel poverty, homes must be energy efficient and have low running costs. Achieving this will result in homes which promote good health, reducing strain on the NHS and carers, particularly over the winter months.

The link between housing and health was not lost on Christopher Addison, former Minister for Health who is famous for the 'Housing, Town Planning, &c. Act 1919' although this is more commonly referred to by its informal name, the 'Addison Act'. This Act led to slum clearances and the creation of mass council housing following WWI which in turn improved the health and quality of life for occupants.

One aspect of household safety which is regularly overlooked in the UK is the risk of overheating. Much work has been undertaken to insulate homes for winter, however 19% of bedrooms and 15% of living rooms are estimated to currently overheat in the UK(45) with this percentage likely to increase as the effects of climate change become more severe. Like cold temperatures, overheating can also cause, risks to health and in severe cases, fatalities.(46) The health risks associated with overheating are, again, further compounded by the increasing proportion of those aged over 65. New builds must be able to retain heat well for winter, while also being sufficiently cool in the summer.

In summary, by creating future-proofed homes, we can reduce fuel poverty and improve mental and physical health, in turn, reducing the associated costs and pressures on the NHS. For example, it was estimated that by improving the energy efficiency of 28,000 homes in Nottingham, the NHS saves an £700,000 per year.(47)

ELECTRICITY

As of 2019, approximately 33% of the UK's electricity consumption is attributed to residential homes, with the domestic sector being the largest end user of electricity. As shown in Figure 8 (below), 43% of electricity is generated from fossil fuels (41% of which is gas), renewables account for 37% and nuclear for 17%.(48)

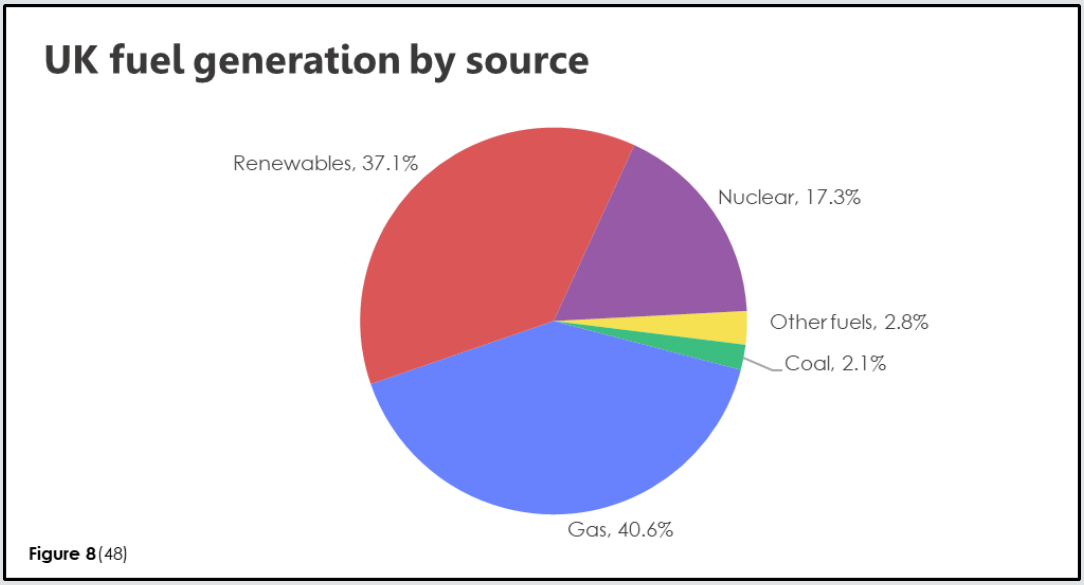


Figure 8(48)

UK electricity consumption is already of great significance, both in terms of its impact on the environment and its increasing cost, which can lead to fuel poverty. Electricity consumption in the UK will only intensify in the years to come, due to the following changes:

- An increasing proportion of the UK's population is aged over 65. A growing number of retirees spending more time at home will put strain on energy demands.
- Increasing temperatures caused by climate change will lead to an increased need for cooling technology, such as air conditioning and fans, which are infrequently used in the UK.
- Gas fuelled central heating is to be discontinued in newly built homes as of 2025, leading to increased demand for electricity to power heating, such as air source heat pumps.
- The UK plans to stop selling petrol and diesel cars by 2030, which will result in a greater uptake in electric vehicles and greater electricity demand.

As described under the sub-heading 'fuel poverty', affordable electricity and heating is crucial to the health and quality of life of UK residents. For low-income households, energy costs are the second largest expense after food (49), so it is necessary to reduce domestic electricity needs as much as possible.

Space heating is the most significant end use of residential energy. This can be combatted by ensuring new homes are well insulated, so that little energy is spent on heating. Other factors are largely dependent on the installation of efficient appliances, though these can be replaced and upgraded more easily than the homes themselves; they are therefore less of an immediate issue when considering housing

design. Nevertheless, the use of efficient appliances should be considered when finalising housing designs.

Ideally, homes would not only be well-insulated for periods of cold weather, but also be capable of regulating temperature to comfortable levels, mitigating the need for air cooling. This will be of greater importance in future decades, as the effects of climate change become more acute.

In regards to housing design, once energy requirements are mitigated to the greatest degree possible, it is recommended that new homes are built to produce energy locally, via means such as photovoltaic (PV) panels. From the perspectives of economic and national security, ensuring a reliable electricity supply is crucial. Some benefits of generating electricity in residential homes, as opposed to by dedicated power stations are outlined below:

- Approximately 8% of all electricity generated is lost in transportation between power stations and consumers. Approximately 1.5% of the UK's greenhouse gas emissions are from electricity lost in transmission.(50) Locally generated electricity, which is not subject to losses during transit, would therefore reduce electricity costs and mitigate emissions.
- Disruption of power stations, particularly for prolonged periods of time, can have large-scale impacts on businesses and the economy. This could occur as a result of damage caused by accidents, environmental disasters, technical issues, or deliberate human disruptions such as, terrorism, foreign sabotage or war. The national security of these facilities is paramount. The vulnerability of the sector was highlighted in May 2021, when the United States' Colonial Pipeline was disrupted by hackers, causing large-scale disruption.
- As national energy requirements increase, so too will the pressure on power stations. Producing energy at the source of consumption would relieve some of this pressure.
- Although infrequent, solar storms can disrupt electricity supplies. Transformers (which are used to transport electricity from power stations to consumers) are particularly vulnerable to these events. A large solar flare, which some scientists predict may occur in the next 100 years, could disrupt electricity supplies on a huge scale and have drastic consequences for the economy.(51,52) The risk of these major outage events can be mitigated by local electricity production, which does not require the use of vulnerable transformers.
- Extreme weather events will become more prevalent due to climate change, leading to more frequent damage to electricity lines. Subsequent disruption can be mitigated by increasing domestic energy production.

Reliable, low-cost electricity is crucial for citizens to enjoy their homes and for businesses to thrive. In the decades to come, electricity will likely become the predominant fuel for all short-mid distance transportation. Our reliance on electricity today, and in the future, cannot be understated.

Reducing residential electricity consumption - by reducing energy requirements and generating energy locally - can mitigate the aforementioned issues and play a part in safeguarding the nation's national security and economic longevity. New builds have a huge part to play in mitigating our energy demands.

SECTION SUMMARY

Many environmental, social and economic issues are intertwined with housing. Housing is crucial to our economy, our health and our society as a whole. A well-thought-out solution to the housing crisis will bring about improvements to many sectors; a poor one would, at best, delay necessary action, 'kicking the can down the road' for future generations to resolve.

A comprehensive approach must be taken so that the key issues are overcome with minimal detriments. Housing can cause many issues, but innovation in the field of housebuilding has the potential to solve many present and emerging problems facing the UK.

SECTION 2

THE SOLUTION

INTRODUCTION

In this section, a solution to the UK's housing and CO_2 crises is proposed. The proposal focuses on sustainable building materials and high-output methods of construction. Due to the comprehensive nature of the review, a number of Secondary Issues are also overcome in this section; those that are not addressed here are overcome in Section 3, Implementation.

MODERN METHODS OF CONSTRUCTION (MMC)

The Farmer Review and the housing white paper 'Fixing the broken housing market', along with numerous other sources, acknowledge that due to labour shortages, homes in the UK must be built in factories to meet national housing demands. MMC is essential in any housing solution, although as outlined previously, the materials utilised in this form of construction must not be detrimental to the UK's environmental aspirations.

Homes built in MMC factories will:

- Require less labour, decreasing build costs and making homes more affordable.
- Be constructed at a faster rate. Yorkshire-based Ilke Homes claim that they build their MMC homes twice as quickly traditional methods of construction.(53)
- Be of a higher quality than traditionally built homes, due to greater use of technology, machinery and increased opportunities for supervision and quality control.
- Be less susceptible to construction delays caused by adverse weather.
- Create less waste.
- Improve health and safety for construction staff.
- Improve the working environment by providing better welfare facilities for workers.

Some issues must be overcome if MMC is to become the dominant construction method in the UK include:

- The sourcing and training of staff.
- The establishment of reliable supply chains for building materials.
- The promotion of consumer awareness and the building of customer confidence.
- Undertaking necessary research and development.

As discussed, MMC construction should be undertaken by a housing developer, as opposed to a contractor who builds MMC homes to sell onto developers. In brief, this approach would reduce build costs by removing a middle-man. Additionally, this provides MMC factories with a predicable demand for new homes which third parties cannot always provide. Predictability is key to lowering production costs and therefore housing costs.

Building homes for the organisation which sells them allows MMC builders to specialise in fewer house types. Concentrating on a smaller number of house types will improve resource

management, build times, build quality, workflow efficiency and costs for both housebuilders and their customers.

Traditional housebuilders are not innovators and typically do not change until they deem it strictly necessary. Should one housebuilder with a significant market share and reputation adopt and profit from the use of MMC, this would be a catalyst for other developers to invest in this method of construction.

OVERVIEW OF 'IDEAL' FUTURE BUILDING MATERIALS

A number of factors must be considered when identifying an appropriate new norm for residential construction in the UK. The method of construction should be the best long-term, sustainable solution for the nation, from economic, social and environmental perspectives.

Traditional construction cannot solve the housing or CO_2 crises, so alternate solutions must enable significant portions of housebuilding to be undertaken in factories, utilising minimal labour and high-precision technology. Traditional building materials, such as steel, concrete and bricks, should henceforth be avoided, due to their costly environmental footprints: these materials emit vast quantities of greenhouses gasses and consume large volumes of water when produced. Furthermore, the immense weight of these materials necessitates substantial foundations to support their loads, whereas light-weight buildings require less substantial foundations. As foundations are typically concrete, this further reduces greenhouse gas emissions and water usage. Lighter building components are also cheaper to transport and easier to assemble.

Construction waste is also of significant importance and must be carefully considered. Any home we build today creates waste from offcuts, overordering and building material damage. Construction's main waste, however, is the waste legacy of the building itself, which will eventually become redundant and require demolition, leaving a waste legacy for future generations to inherit. We must consider how useful or detrimental our construction waste is for future generations. Ultimately, given the exponential pace of technological development, we cannot predict what materials will be of use to our descendants, so it is therefore the safest course of action to favour biodegradable or recyclable materials.

Some materials are not as environmentally friendly as they first appear. For example, mineral wool insulation has some environmental benefit as it is made from waste materials. Unfortunately, energy is required in its manufacture and it can only be recycled to make more insulation or as a strengthening agent in concrete. Outside of construction, it has no other uses. Once buildings constructed with this material reach the end of their life, is it is unlikely that these materials will be recycled. This is because it is a time consuming, laborious and costly undertaking to filter through demolition waste to sort materials for recycling. As a result, traditional building materials like mineral wool are often sent to landfill. If the contemporary construction industry cannot dedicate recourses to effective demolition waste recovery, we cannot rely on future generations to do so either. The most appropriate course of action is therefore to prioritise natural building materials which will biodegrade following a building's demolition.

Moving forward, construction materials must be sufficiently strong, long-lasting and safe to residents and the environment, while providing sufficient thermal and acoustic insulation. Crucially, building materials must also be low cost now and remain at low cost in the future, to ensure that housing remains affordable in the long-term. Building materials must be suitable for the UK's climate today and that of a changing climate which experiences more extreme weather events. Ideally, construction materials should be UK-sourced, to create employment opportunities and reduce transportation emissions and costs. Crucially using UK-sourced building materials will improve build cost certainty. Imported building materials are subject to greater price volatility, which reduces the reliability of build costs and increases the risk of housing affordability issues. Given the pressing timescales for adoption, the ideal building method must also be suitably tried and tested to provide a degree of certainty that it can be mass produced in the UK.

The most appropriate building material for our needs and the needs of future generations are natural ones. Natural building materials, rather than emitting greenhouses gasses during production, store them: this is often referred to as a 'carbon bank'. Timber, for example, comprises of around 50% stored carbon by weight.(13) Natural materials also biodegrade when disposed of, meaning that there is no waste legacy - with the exception of delayed carbon emissions - for our decedents to inherit. This approach would create a suitable full lifecycle or 'cradle to grave' solution for UK housing; absorbing carbon dioxide into the fabric of our buildings for the duration of their lifetimes, and significantly reducing construction waste.

There are numerous natural building materials, so we must consider which of them can be reliably produced in the UK. Before the industrial revolution, UK homes were built in 'vernacular architectural', whereby locally sourced materials were utilised in construction, which created localised housing styles. Materials were not transported over long distances, making them more environmentally friendly in one aspect. Times have changed, and a modern solution must be scalable and applicable nation-wide. Localised architectural styles would be inefficient, as labour would be less transferrable between regions when coping with varying demands. Furthermore, lower build costs are created by manufacturing on a large scale. To summarise, the chosen natural building material must be in sufficient supply to meet national demands.

NATURAL BUILDING MATERIALS OVERVIEW

There are a number of natural building materials, each with their own benefits and considerations. Some materials, such as cob, have been used for thousands of years and are still used today in much of the world. Cob's key component materials are earth, straw, water although other materials are commonly added. Although cob has beneficial properties it does not store as much carbon dioxide as alternative materials, and is difficult to construct in factories. Timber is another excellent building material, but the UK imports much of its timber from overseas.

Many have hailed timber-framed properties as a solution to the UK's housing crisis. While these homes are better for the environment and often quicker to build than traditionally constructed homes, this solution still has flaws. As only the frame of a building is timber, walls must be filled

with other materials such as man-made insulation, this is poor for the environment and neglects the opportunity of further carbon capture within the walls. Moreover, there is an ongoing timber shortage which is leading to rising prices. Sufficient timber is not available in the UK to meet demands. High demand increases build costs and subsequently house prices, compounding the housing crisis.

Hemp is another natural building material. It is lightweight and has excellent building qualities. Many experts have advocated for a greater use of hemp as a building material in the UK. Problematically, hemp is currently not commonplace in the UK, and would have to be grown on our nation's limited agricultural land. The UK already imports 45% of all food consumed from abroad,(54) and replacing our existing edible crops with non-edible hemp would be counter-productive. Furthermore, the environmental impacts of planting large quantities of hemp are unknown given its limited cultivation in the UK.

Fortunately, there is a natural building material available to the UK which meets the extensive list of requirements. The solution to the UK's housing and environmental crises: the humble agricultural by-product, straw.

THE SOLUTION

Agricultural straw is abundant in many regions of the UK, particularly in the east of England, with large surpluses in Lincolnshire, Yorkshire and East Anglia. Cereal crops, such as wheat, barley and oats, are harvested for food with straw being an often wasted by-product. The upper part of cereal crops is edible while the lower, non-edible stalk at the base of the crop is straw. Typically, straw accounts for ~55% of a crop yield by weight.(55) Hay, which is often confused with straw, is dried grass used as animal feed. Straw is collected in bales which are light in weight for their relative volume. Its low cost and high volume means it is not financially viable to transport straw over long distances. Some straw is ploughed back into the land to provide nutrients for the soil. Other uses of straw include animal bedding and biofuel, although large surpluses are available despite these uses. Farmers, who are highly subsidised at present, will also increase their incomes as the demand for straw as a building material grows.


Source: Unsplash

Straw has excellent qualities for building. It has been used in construction for thousands of years, typically as a component in cob houses in order to bind earth together. More recently, the invention of straw baling machines has enabled the construction of load-bearing straw homes. These were pioneered in Nebraska, USA in the late 1800's, during a period when timber demands could not be met. A revival of straw building has come about in recent decades given its low cost and environmental benefits. The first straw bale house in the UK was built in 1994.(56)

Straw is deceptively strong. Many homes, including those first built in the USA, utilise straw as a loadbearing material. Straw walls are made strong by their high density, and are more than capable of supporting heavy loads, including that of roofs. These load-bearing straw homes comprise of cuboidal bales, laid on top of one another in a similar fashion to bricks. This is often referred to as "Nebraska-style", or "load-bearing" straw construction. This method is low-tech and low cost.


Source: The Self Build Guide


Source: The Self Build Guide

Straw has a long life, and like timber, it will not biodegrade unless damp. Straw-bale homes can be built on-site so long as the straw does not become wet. Unfortunately, such an undertaking requires tradespeople who are experienced in straw-bale construction; a scarcely practiced skill in the UK. If load-bearing straw homes are built by unexperienced individuals, as would be the case if the industry expanded rapidly, there would likely be construction errors that lead to damp and decomposition.

Load-bearing straw construction is less labour intensive than traditional construction, as straw bales are far larger and lighter than bricks and concrete building blocks. Straw bales do not require mortar to hold them together, further reducing labour and material requirements. Despite these benefits, the quantity of on-site labour and training required renders traditional straw-bale construction incapable of solving the UK's escalating housing crisis. The existing pool of experts is likely too small to expand the industry at the required rate, while also ensuring high build quality.

A modern alternative to on-site straw-bale construction is factory-based straw construction. This involves pre-made sections of a building (such as entire walls, known as panels) being comprised of straw bales with a timber-frame. These panels are structural, insulative and provide a dry housing for the straw.


Source: LILAC (Low Impact Living Affordable Community)

It should be noted that the timber used to encase these panels is substantially less than that required in timber-framed construction. This method of building has already been undertaken in the UK, with the majority of the construction process taking place in a factory-setting. There is currently no accepted terminology for this form of construction, therefore it is hereon referred to as modern methods of straw construction (MMSC). MMSC offers the speed and reduced labour requirements of MMC factory-built homes, combined with the environmental benefits and carbon sequestration of straw homes.

The Bristol-based company Modcell have built several residential and commercial buildings using MMSC, with notable residential examples in Bristol and Leeds. Modcell have benefitted from government grants and academic expertise from Bath University.(58) A Lithuanian-based business named EcoCocon have also supplied similar MMSC homes to a number of EU and UK-based projects. MMSC building materials remove carbon from the atmosphere, storing it for the duration of their lifetime. This is contrary to most traditional building materials, which emit greenhouses gasses when manufactured. The average UK home emits 50 tonnes of CO_2 in its construction, whereas a typical 3-bedroom straw house stores 7.5 tonnes of CO_2.(56) Below, Figure 9 shows the CO_2 emissions of common building materials compared with straw. Once these homes come to the end of their life, the timber and straw can be utilised as biofuel or left to

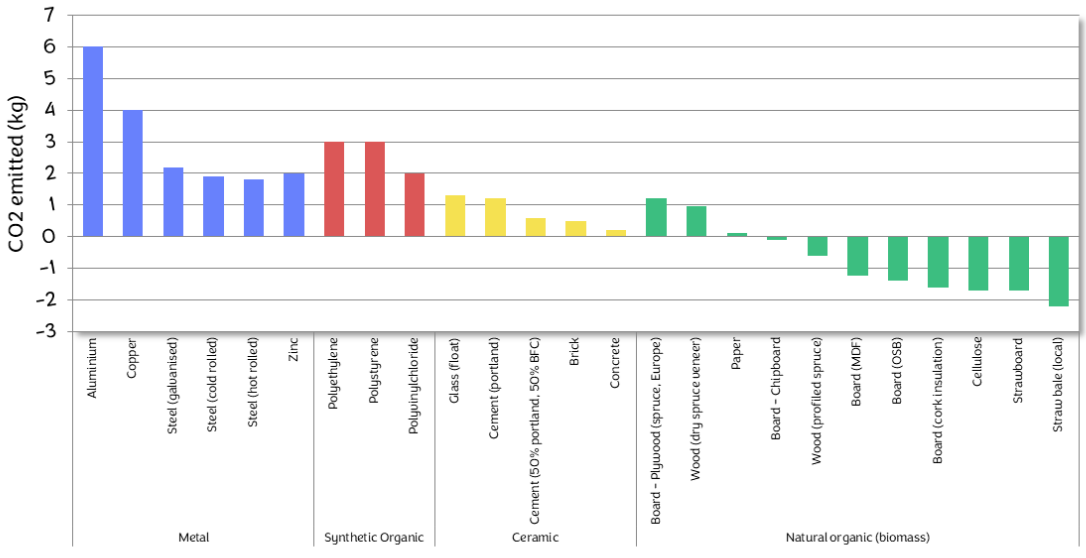


Figure 9 (60)

biodegrade. It is estimated that 13% (36 million tonnes) of all products sent to UK construction sites end up in landfills without being used.(59) MMSC will drastically decrease this figure by way of improved MMC factory efficiencies. The majority of waste produced from MMSC is also biodegradable.

Straw is abundant in the UK, with most experts agreeing that enough straw is available to build in excess of the 300,000 homes per year to satisfy housing demands. Unlike traditional building materials, straw does not require any additional processing, reducing its environmental impact, labour requirements and production cost. As a by-product, straw does not require any additional water in its manufacture either, alleviating growing water scarcity in the country.

It is estimated than under 1,000 straw homes exist in the UK today, with only a small number of these being MMSC homes. The precise numbers are unknown as these have typically been built as self-builds by environmentalists.(56) Part of the reason for its slow uptake has been the minimal awareness of straw as a method of construction, even within the construction industry.

Given its small-scale use, straw-built homes are typically formed by stacking straw bales on top of one another and fixing them together using wooden stakes. Homes are then rendered and plastered with lime or clay. The use of lime and clay plasters enables the building to 'breathe', enabling moisture to escape walls and preventing damp. Gypsum and cement, which are utilised extensively in traditional construction, are not breathable materials, and can cause damp in both traditional and straw homes. Damp in the walls of a straw home can cause the straw to biodegrade.

Straw-built homes have been positively received by inhabitants, particularly due to their effective thermal and acoustic performance. Anecdotal accounts from straw-home occupants have suggested that they also enjoy good air quality and are less likely to experience 'sick building syndrome'. This is particularly beneficial given the trend towards working and studying from home.

There is scope to improve straw construction beyond its current performance. Agricultural bailing machines are not designed to produce straw bales for construction. Research undertaken by the University of Bath found that changes in baling practises can improve the characteristics of straw for building purposes. This would involve reorientating straw within straw bales to maximise insulation potential.(60) With further research and development,

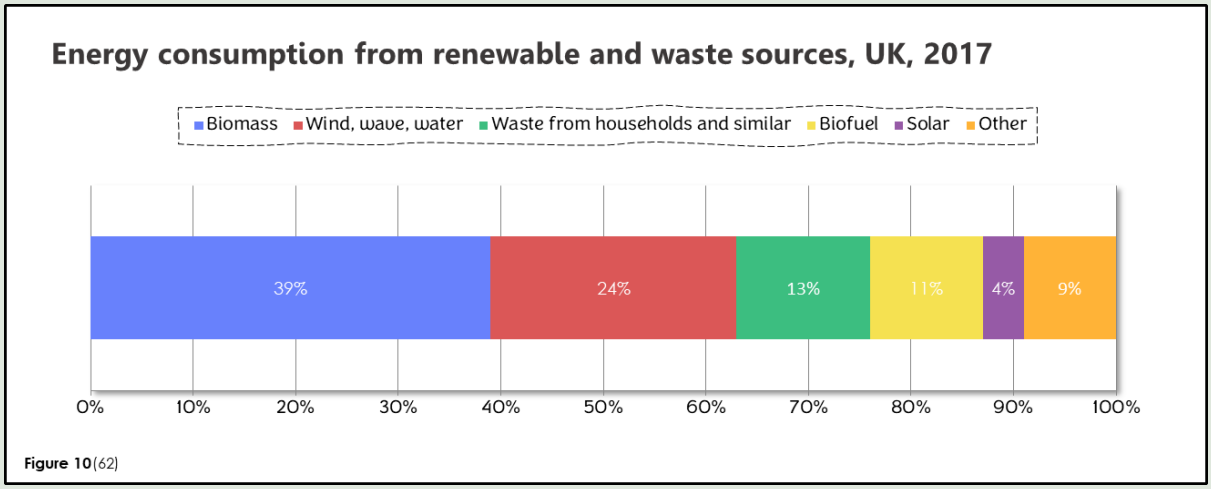


Figure 10(62)

agricultural balers could be designed to create an optimised straw bale for construction use. Farmers would be incentivised to invest in such equipment due to their straw's subsequently increased value. Straw bales could be reduced in width, reducing wall thicknesses while making for similar, if not improved insulative qualities due to improved straw orientation.

Improved straw bale size standardisation and tolerances would also be beneficial to the construction industry, as there are currently varying shapes and sizes of bales which inhibit build quality and efficiency. Low demand for straw in construction has not brought about this change to date, but increased demand will incentivise investments in standardised equipment. This solution to redesign straw baling machines would be far more effective than attempting to resize and reorientate straw bales in a factory setting, as this would require costly machinery, labour and time. Loose straw is also a fire hazard. Regardless of whether standardised balers are adopted, straw is still an excellent building material in its current format.

Due to its high availability and low-cost, straw has already been identified and utilised as a biofuel in the UK. Biomass provides more of the UK's energy than any other renewable source - accounting for approximately 40% of all renewable energy (as shown in Figure 10) - with the majority of biofuel being imported from overseas. Biofuel is mainly imported from the USA and Canada, with 8 million tonnes of wood pellets imported in 2018 alone.(61) Furthermore, quantities of imported wood pellets are increasing steadily as shown in Figure 11. This makes the UK reliant on overseas fuel and therefore subject to price volatility and potentially political exploitation. The environmental sustainability of these products is also being reduced due to their long-distance transportation. Despite this, biofuel is still far more environmentally friendly than fossil fuels. By building homes from timber and straw, this provides a potential future source of biofuel. Offcuts from manufacturing MMSC homes can be used as biofuel immediately; greater volumes of biofuel will become available once MMSC homes reach the end of their life and they are demolished.

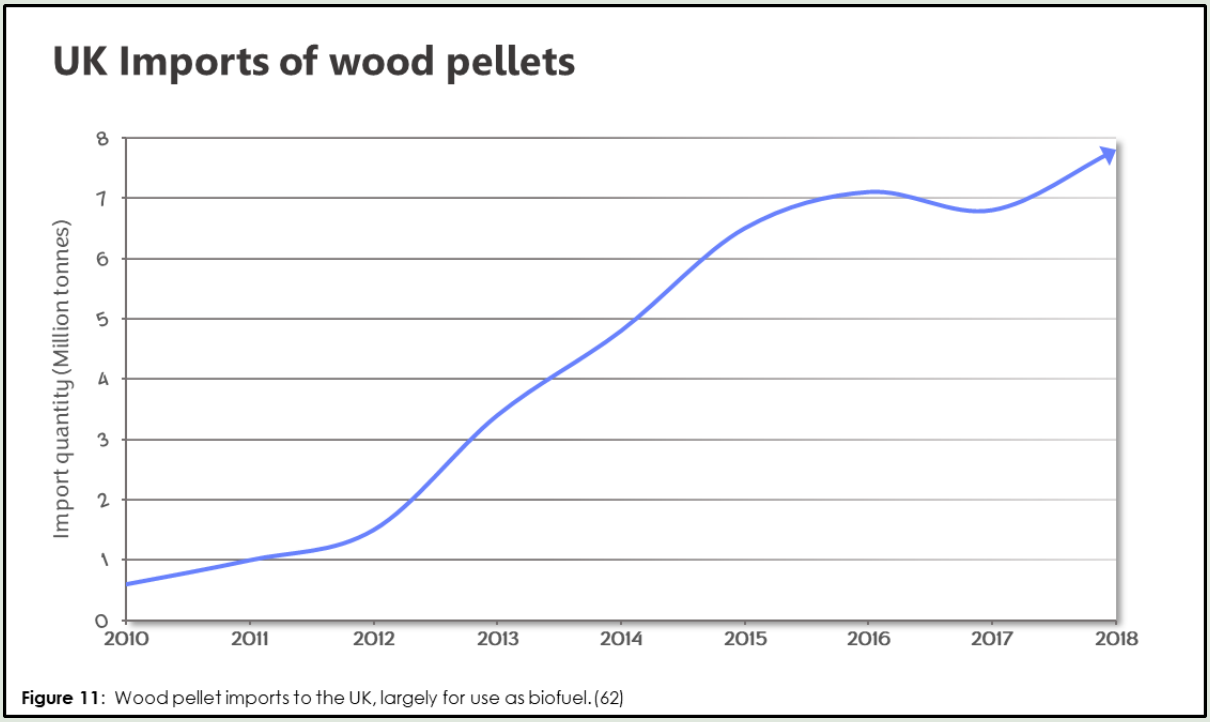


Figure 11: Wood pellet imports to the UK, largely for use as biofuel. (62)

STRAW

WHAT IS STRAW?

Agricultural straw is the stalks that remain following the harvest of a crop. In the UK, straw largely originates from the cereal crops wheat and barley, and from the oilseed rape. Straw is routinely produced as a by-product each August, when crops are harvested. Straw is also *"virtually identical to wood in chemical composition"*,(62) comprising of approximately 50% carbon by weight. When crops are harvested, their valuable elements are removed leaving behind straw, which has low economic value in the current market. Thereafter, it is baled for later use as animal bedding and feed, used as biofuel, or left to decompose in its field of origin, to return nutrients to the soil.

Laypeople often confuse straw with hay: a grass which is an important source of animal feed. Although straw provides a source of roughage for animals its use as feed is limited.

STRAW AVAILABILITY

To date, straw-bale construction in the UK has primarily used straw from cereal crops. Research and development in Europe and North America also focusses on these sources of straw.

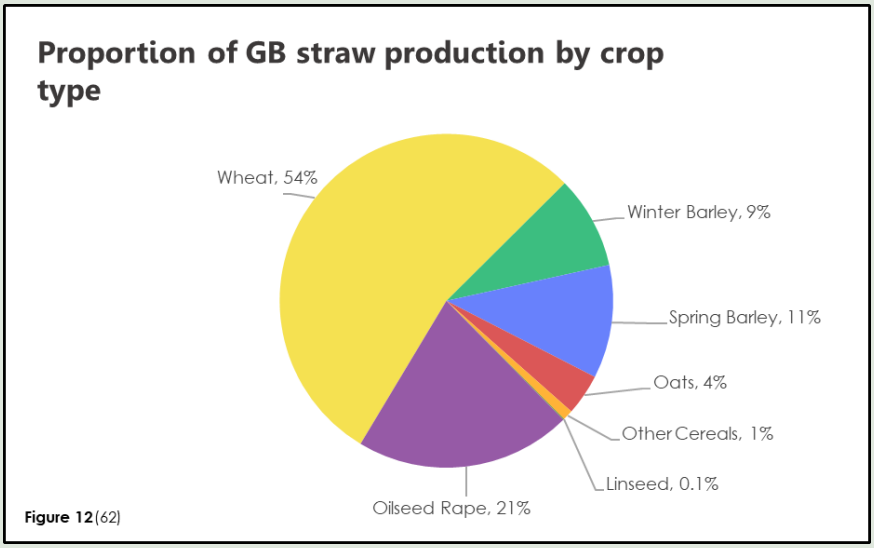


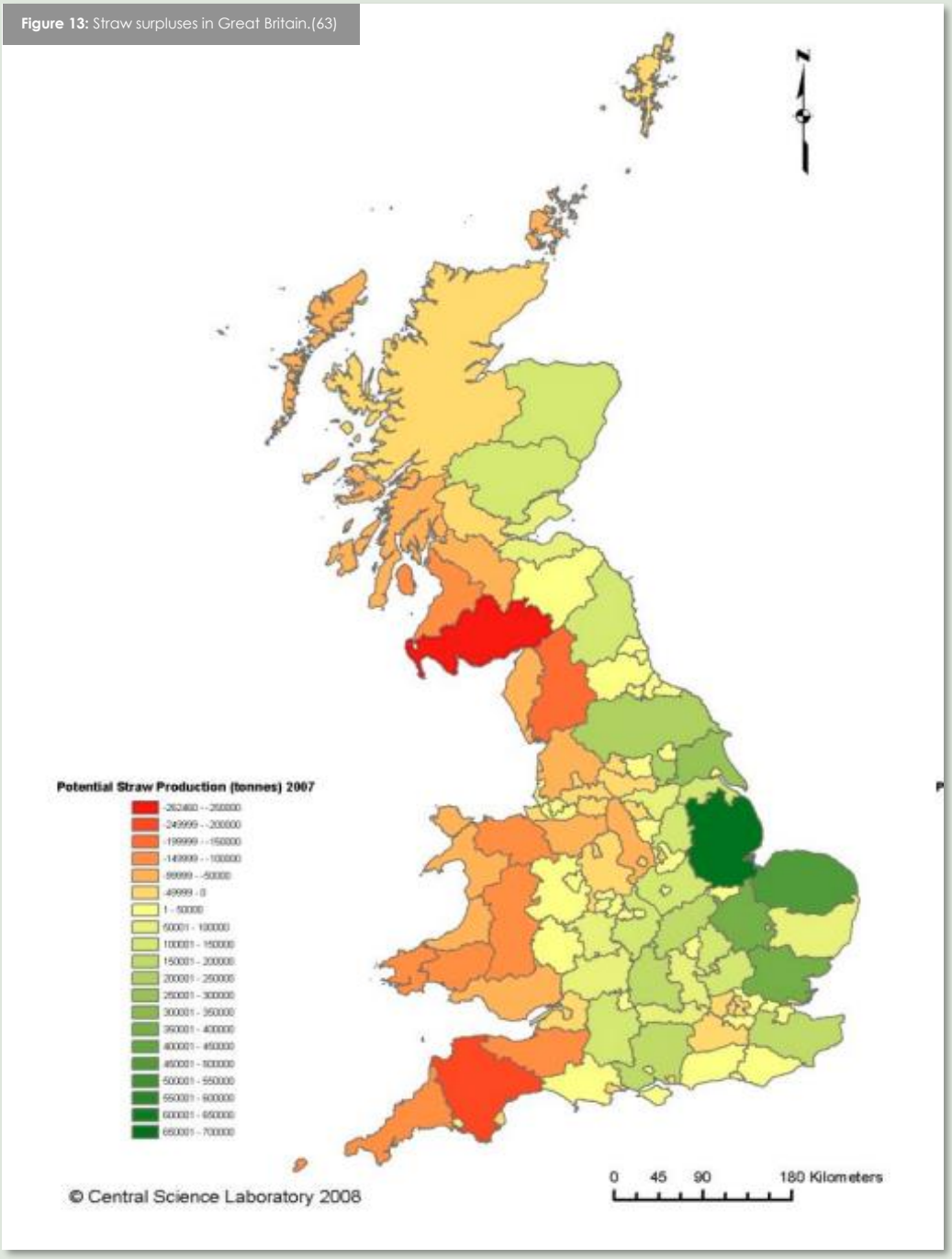
Figure 12(62)

From Figure 12, it can be seen that wheat straw accounts for 54% of all straw produced in the UK. Rapeseed, an oil crop, accounts for approximately 21% and its usage in construction has been limited thus far. Rapeseed straw is also a worse material for animal bedding and roughage feed when compared with cereal crop straws. Ultimately, rapeseed straw does show promise as a biofuel which would avoid this straw being wasted.(63)

When assessing the quantity of straw required to meet the UK's large-scale construction needs, this review focusses on cereal straws, as they are better researched and more widely used in construction. With further research and development, rapeseed straw may also be utilised as an effective building material, but until then, it remains an unnecessary risk when compared to tried and test cereal straws.

Figure 13 identifies the areas of the UK which have surpluses and deficits of cereal straw production when accounting for livestock bedding demands. Generally, the east of Great Britain has far greater straw yields than the west.

Figure 13: Straw surpluses in Great Britain.(63)



Research indicates that Scotland and Wales have overall straw deficits, with both nations importing straw from adjacent regions, such as the west midlands and the north-east of England. Regions with true straw surpluses are Yorkshire and the Humber, the East Midlands and the East and South-East of England.(63)

Figure 14 shows that straw yields have been relatively consistent in recent years, although variations may occur as a result of abnormal weather events, which are becoming more common as climate change intensifies.

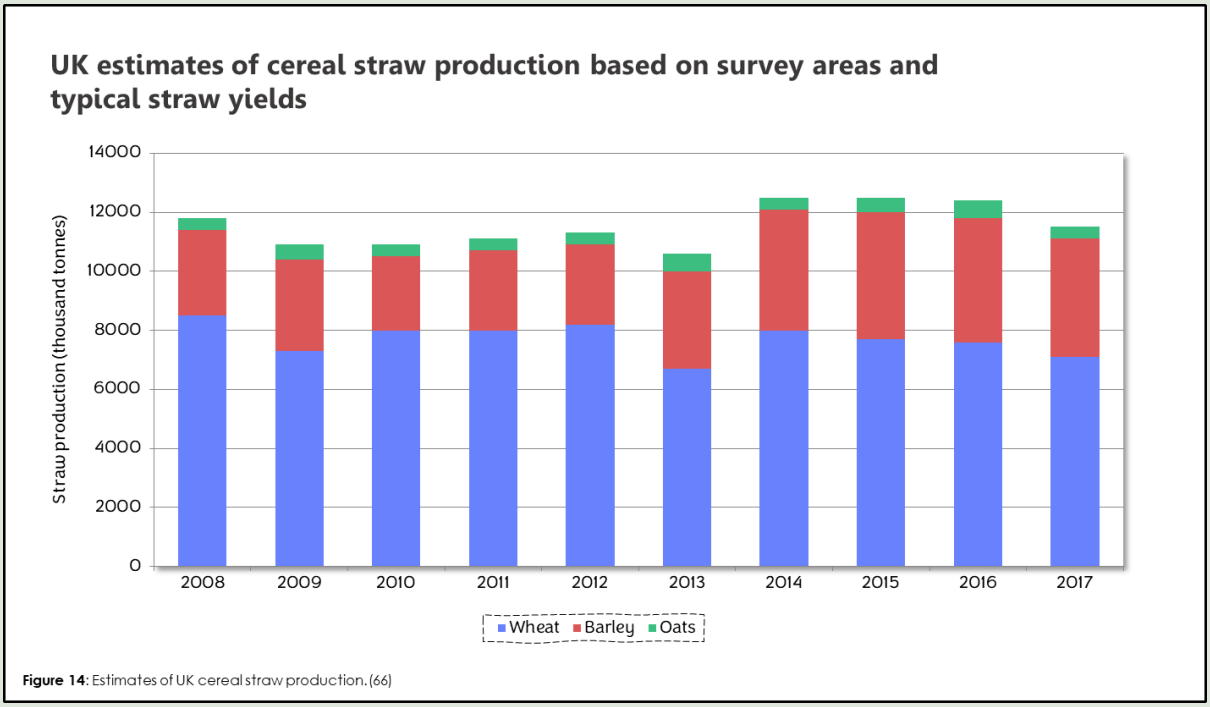


Figure 14: Estimates of UK cereal straw production. (66)

Approximately 11.7 million tonnes of baled cereal straw was produced in the UK in 2017. This figure represents around 60% of the total straw yield, as not all straw is baled; the remaining 40% is ploughed back into fields to decompose, providing nutrients for future crop growth. The two main uses of baled straw are livestock bedding and feed.(64) Straw is currently fed to livestock as a source of long fibre, which is an essential part of the diet of ruminant livestock (cattle, sheep etc.). Roughage - which could be straw, hay or silage - typically comprises a minimum of 10% of their feed ration. Wheat straw has a lower feed-value than barley or oat straw, but is widely used for animal bedding for cattle, pigs and horses.(63)

The abundance of wheat straw in the East of England, and its low value as feed, makes it an ideal building material. 730,000 tonnes of straw (6% of total straw production) was used as fuel in biomass power stations in England in 2016/17. This comprises the largest use category after bedding and feed, with all other end uses accounting for less than 5% of UK straw usage. Data suggests that there is a significant net surplus of straw in the UK. As straw is bulky and costly to transport, most straw usage occurs close to its source. There can be substantial regional variations in the straw supply-demand balance.(64) In the absence of nearby livestock or other markets for straw, it is typically ploughed back into soil for disposal.(63)

As shown in Table 1, 24% of all baled straw was surplus to requirements in 2017; this equates to 2,871,000 tonnes of cereal straw. This raises the question, is there sufficient straw for the UK housing market?

Table 1: Estimates of UK cereal straw supply and demand, 2017 (66)

UK Supply / Demand	Thousand tonnes	% of cereal straw production	Implied cereal area ('000 ha)
Cereal straw availability	11720		3142
Cereal straw usage:			
Animal bedding	5800	49%	1554
Animal feed	2000	17%	536
Mushroom industry	40	0.3%	11
Carrots	250	2%	67
Power stations	730	6%	196
Export	39	0.3%	10
Surplus cereal straw resource available in the UK for other markets	**2871**	**24%**	**769**

At present, the UK aims to build 300,000 new homes per year. Ideally, there will be enough straw to construct more than 300,000 homes per year, to account for increases in housing demand in the future. Straw construction expert Barbara Jones estimates that an average load-bearing, 3-bedroom straw house utilises approximately 350 straw bales, which weigh an average of 25kg each.(56) As shown in Table 1, a surplus of 2,871,000 tonnes of cereal straw was produced in the UK in 2017. Based on the assumption that an average straw home is 3-bedrooms and requires 8.75 tonnes of straw to build, as per Jones' calculations (350 x 25kg), this would mean that approximately 328,000 new load-bearing straw homes could be constructed each year. Straw homes alone can therefore satisfy the UK's housing demands, even if traditional housebuilding was unexpectedly ceased. It should be noted that Jones' calculation is based on the straw required to construct relatively 'straw-hungry', load-bearing homes, whereas the factory-made MMSC homes proposed in this review will require slightly less straw per dwelling.

Bristol-based MMSC manufacturer Modcell estimate that their 3-bedroom house design requires only 7.2 tonnes of straw.(65) This is slightly less than Jones' estimate, as Modcell's factory-based design utilises more timber in its design. Using Modcell's estimate of 7.2 tonnes, the UK's surplus straw can be used to construct 398,750 homes per year. This figure is well in excess of current housing targets, and will sufficiently satisfy increases in future housing demand. As Modcell construct MMSC homes, their 7.2 metric tonne estimate is most akin to the housing solution proposed in this review. In either scenario (Jones or Modcell), sufficient straw is available to meet the UK's housing needs.

The surplus of straw from cereal crops is estimated to be sufficient to construct 400,000 homes per year: this is more than enough to satisfy the UK's target of 300,000 homes per year.

ENVIRONMENTAL

Most agricultural soils do not contain enough naturally occurring nitrogen to meet crop growth needs throughout the growing season, necessitating supplementary nitrogen applications each year. These are typically applied in the form of mineral and organic fertilisers, such as manures and livestock slurries. Nitrogen usually has a large and immediate effect on crop growth, yield and quality. The use of fertilisers can have an adverse impact on the environment, particularly as they drain into water courses in a process known as eutrophication. Environmental damage from fertilisers can be mitigated with modern farming techniques, and improvements in agriculture are continuously being made. For example, modern manure injectors improve slurry penetration into the soil, while reducing the risk of run-off into waterways.

Regardless of the construction industry's intentions, it must be acknowledged that straw remains a by-product. It will be produced by agricultural activities whether it is being utilised by housebuilders or not. It is fair to suggest that any environmental damage caused by crop and straw production is not the fault of the construction industry, though there may be collaborative efforts to prevent ongoing damage when agriculture and construction become more intertwined.

INVESTING IN UK FARMING

Farmland occupies 71% of the UK's landmass and provides employment for 1.4% of the nation's workforce (472,000 workers). Despite this, agriculture accounts for only 0.5% of the national economy. When assessing the profitability of farms, the Department for Environment, Food and Rural Affairs (DEFRA) uses the index Farm Business Income (FBI), which considers unpaid farm labour (such as that of the farm owners) and capital invested. In 2020, over 20% of farms did not make a positive FBI and only 26% of farms made a FBI in excess of £50,000.(66) Wages per hour for those working in farming are also the second lowest of any sector in the UK.

Farming's contribution to feeding the nation cannot be understated, but its low profitability for the high volume of resources required highlights the sector's inefficiency. The necessity of the nation's food requirements combined with the sector's poor profitability have led to many farms relying on government subsidies. UK farmers received £3,165 million worth of subsidies in 2020 alone.(67)

In addition to farming not being as profitable as many other sectors, it also only supplies 55% of UK's food, with 26% sourced from the EU.(54) This high level of reliance on imported food exposes the UK to several issues, including a risk of fluctuating food prices caused by disruption to imports (via economic, environmental and political changes), reduced food lifespan due to transport times, increased congestion and increased emissions from transporting food over long distances. The international shortage of lorry drivers is one such example of how food imports can be adversely impacted.(68)

When the UK invests in MMSC, the demand for straw will increase, leading to an increase in its price. This increased value of straw will make farming more profitable, reducing the sector's reliance on government subsidies. Alternatively, this revenue could be used to invest in farming efficiencies to increase outputs and farming revenue.

An increase in farming profitability would result in increased wages and drive further investment and economic growth.

Investing in farming innovation could see more food grown in the UK, generating employment, increasing farming revenue, reducing farming's environmental impact and reducing the UK's reliance on imported goods. Increasing the UK's food production will not only safeguard our future in a world where climate change and a growing population could see food shortages, but it could also see the UK capitalise on the opportunity. If the UK invests in farming efficiencies now, partly fuelled by a growth in farming revenue from increasing demands for straw, it could see the nation become a net food exporter. These benefits meet the government aspirations to 'build back greener', 'level up every part of the UK' and invest in science and technology.

It is proposed that the government should provide sufficient financial benefits, such as grant funding, to incentivise a UK-based manufacturer to design and produce a new generation of straw bailers. The objective should for these new straw balers to produce optimised straw bales for MMSC construction. This approach offers a great opportunity for the UK. MMSC homes could be made to even higher standards and with greater thermal efficiency. MMSC baling machines could also serve as a valuable export to nations seeking to follow the UK's lead and build MMSC homes. There is no detriment to producing a surplus of MMSC straw bales as these can still be utilised for other purposes.

Efforts to produce a new generation of MMSC straw balers compliments government objectives to 'level up' and 'build back greener'. Grant funding to assist in the design and production of MMSC balers could also be conditional on factories being established in areas of high unemployment and where local skillsets would complement the business.

BIOFUEL

Cereal straw is currently used in the UK as a biofuel, but this application is declining as wood pellets become the preferred option.(69,70) Wood pellets are mainly imported from Canada and the USA.(71)

An estimated 96,000 hectares of UK land (1.6% of all arable land in the UK) is used to grow crops for bioenergy with approximately 11% of this being wheat.(72)

Although straw offers a benefit as biofuel, it is not as environmentally friendly as utilising straw for construction. When burned, biofuel is carbon neutral, releasing its stored carbon into the atmosphere. Although this is preferable to burning fossil fuels, it still results in carbon being released into the atmosphere over a short time frame. Utilising straw in construction means that carbon can be stored for the duration of a building's lifespan. This approach offers greater environmental benefits than biofuel, as carbon can be stored at a time when the world is vulnerable to CO_2 emissions. Carbon would then be released at a later date, when GHG concentrations have declined. Straw homes acting as long-term carbon stores would be an excellent 'quick win', offsetting carbon emissions while the world adapts to low carbon technologies.

Should the demand for straw in biofuel power stations increase, a plentiful supply of straw for construction can be retained by using non-cereal straw as biofuel, while reserving cereal straw for construction use.

TIMBER AVAILABILITY

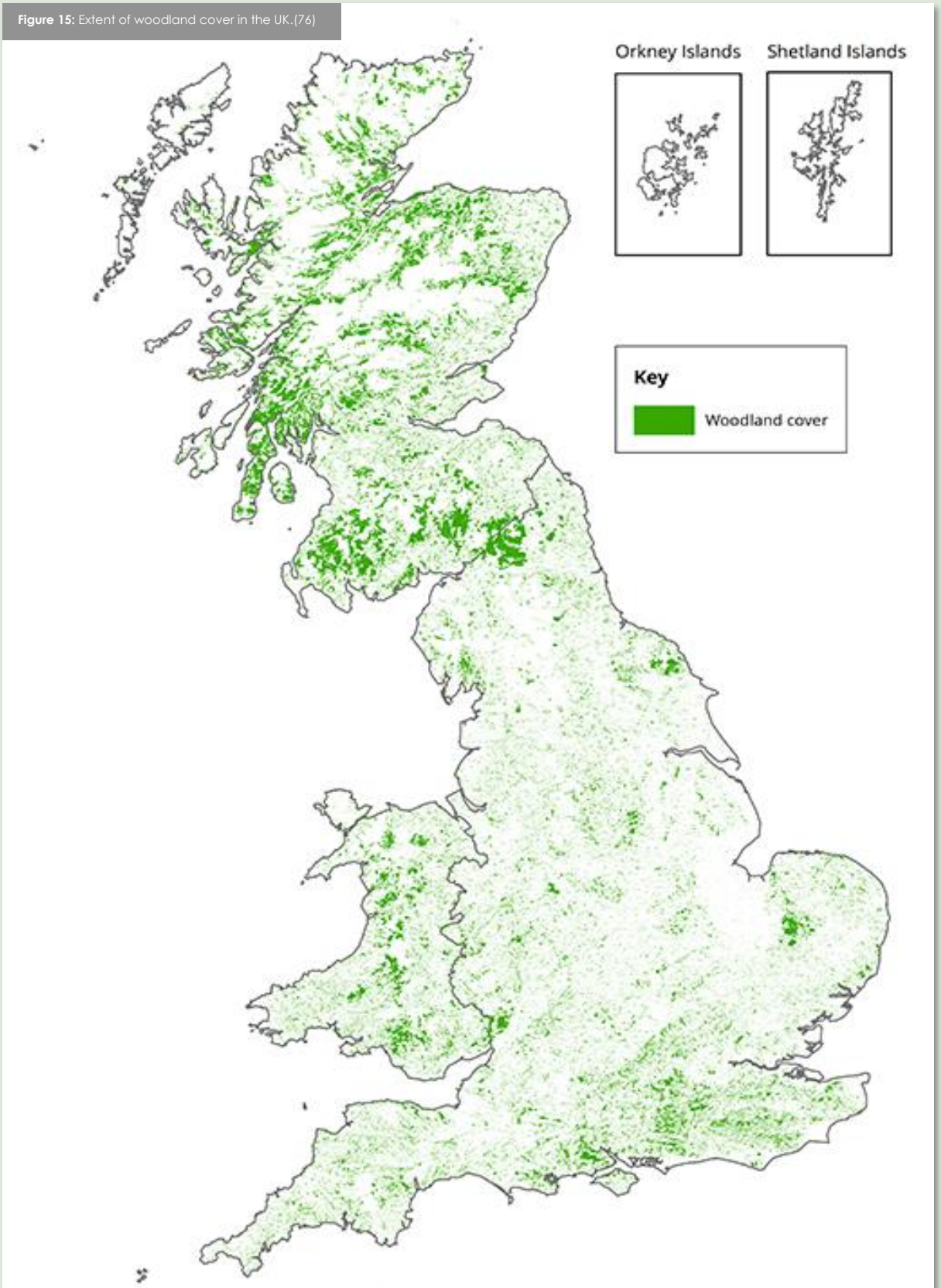
Many have advocated for greater use of timber in residential construction, principally by building more timber-framed homes as a means of sequestering carbon to combat climate change. Timber, like straw, stores carbon for the duration of a building's lifetime. Approximately 50% of timber is stored carbon by weight.(13) Unfortunately, UK timer stocks are lacking. The UK is one of the least densely forested countries in Europe, with an estimated 13% of forest cover. This compares with 46% for Europe as a whole and 31% worldwide.(17) The UK is in a substantial timber deficit, being the second largest net importer of forestry products in the world, second only to China.

Net forestry imports are currently at the value of US$8.4 billion annually.(17) As emerging economies become more developed, their desire for greater quantities of timber will also increase, further increasing demands and prices. This shortage will be further compounded by a growing global population. Climate change may also cause temperate regions to become inhospitable to softwoods, such as conifers, which are commonly used in construction; this would further reduce global timber stocks.

Although timber is an excellent building material, insufficient UK quantities of timber are likely to pose a significant challenge to sustainable housing goals. Rising timber scarcity and subsequent price increases would lead to increased construction costs and house prices. Timber scarcity may become so severe that construction may come to a standstill, as has been the case in recent years.(73,74) Load-bearing straw construction requires significantly less timber than traditional timber-framed properties. MMSC would therefore improve build costs and reduce the risk of supply chain disruption.

Forestry provides employment for an estimated 18,000 workers.(75) The number of sawmills in the UK has declined by 20% in the last decade from a total of 183 in 2011 to 147 in 2020.(75)

Figure 15: Extent of woodland cover in the UK.(76)



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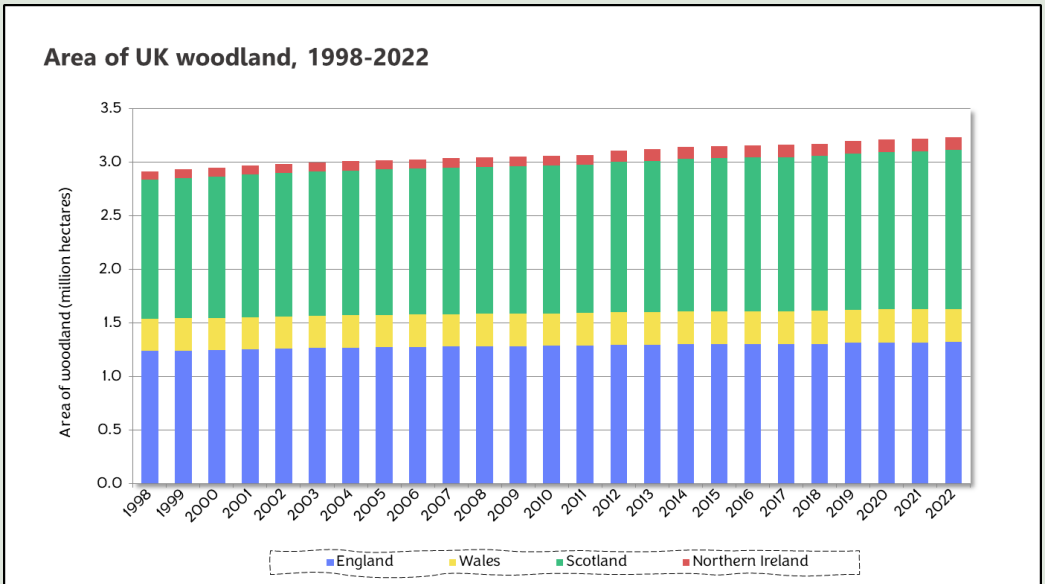


Figure 16: Woodland area of UK countries.(77)

Scotland has a higher proportion of existing forest cover than other UK nations and its forest cover is increasing at a far faster rate.(76,77) As displayed in Figure 16, new trees have been planted on over ten-thousand hectares of land in Scotland annually since 2018.(77) Scotland's high rural population makes it a logical location from which to source timber for a new generation of MMSC homes in the long-term. Investment in forestry would also be well suited to new woodlands, such as the Northern Forest, which could become a major supplier of timber in the near-future. An increase in tree cover could increase nature tourism, while logging provides employment and economic stimulus in rural locations.

It is acknowledged that it will be decades before domestic timber is available in sufficient quantities to meet housing demands, even when utilising low-timber MMSC. Once achieved, transport costs and emissions will be reduced, while carbon storage, employment in rural areas, and natural recreation opportunities all increase. These outcomes contribute to the government's 'levelling up' agenda.

In the short to medium term, timber supplies for MMSC homes will have to be imported from overseas. Timber imports have increased significantly in the past decade, with approximately 5,000m³ of sawn wood timber imported in 2011, rising to approximately 7,200m³ in 2020; an increase of 44%. All other categories of timber imports (such as wood-based panels and wood pellets) have similarly increased in this timeframe. The only timber import category to have reduced in this timespan is that of pulp and paper, likely due to modern paperless working practices, digital news and electronic books.(78) Sawn softwood is mainly imported from northern Europe, with Sweden accounting for 41% of imports, Latvia for 20% and Finland for 12%. Principle exporting nations of particleboards are Germany (20%), Latvia (18%) and Ireland (17%).(78) Constructing MMSC factories in areas of straw surplus would reduce transport times, costs and traffic congestion.

As previously outlined in this report, the greatest straw surpluses are in the East Midlands and East of England, with smaller surpluses in the Yorkshire and Humber and South East regions. Straw is of low value for its volume, so transporting straw over large distances is impractical and inefficient.

STRAW STORAGE

Straw is harvested in August each year, although construction must be enabled all year round. This poses a difficulty regarding straw storage. A small amount of straw is required at MMSC factories for immediate work. Large additional quantities must be stored for the remainder of the year, until the next harvest is gathered. Straw could be stored in an appropriate, dry location at the farm at which it is harvested or in substantial quantities at MMSC factories. The latter could offset price volatility and ensure optimal storage conditions. Adversely, storage costs would be high and measures would be required to mitigate the risk of large-scale straw loss, such as that caused by water or fire damage. Storing straw in several separate buildings would largely overcome this risk.

Straw storage requirements at MMSC factories could be reduced by paying farmers lower prices in August, immediately following the harvest, and higher prices later in the year. This would incentivise farmers to store straw, and reduce MMSC factory storage costs and risk. A thorough analysis of all available options is required to ensure construction costs are minimised.

PERCEPTIONS OF MMSC

Interviews with members of the public and property and construction professionals have identified a number of common concerns regarding MMSC. Most of these concerns focus on straw as a construction material, as opposed to the factory setting.

Large, quantitative-based research regarding the public's perception of straw construction is in limited supply, though a questionnaire, shared via Facebook and completed by 381 individuals in 2009 shows the following results:

Table 2 shows that the majority of people would live in a straw-built home, however, those with prior knowledge of straw as a construction material are more likely to do so.

Qualitative research was undertaken as part of this review, whereby a range of professionals and members of the public were interviewed. Concerns from both professional and public groups were raised regarding straw use in construction. Several main themes were identified:

- Structural longevity and capability
- Fire risk
- Straw biodegrading prematurely
- Rodent and insect infestation

Concerns from the public were largely contained to the above four categories. Professionals sometimes voiced more technical concerns; most of which have been addressed under the heading 'Housebuilders' in Section 1 of this review.

Table 2: Public opinion of straw in construction (79)

		Would the participant consider living in a straw dwelling?	
		Yes	No
Was the participant previously aware of use of straw in construction?	Yes	85%	15%
	No	66%	34%
	Total	80%	20%

Furthermore, some professionals who were confident in MMSC's capabilities themselves were sceptical that the general public would want to live in MMSC homes. When asked why, they identified the same key areas of concern.

In order for MMSC to thrive in the private housing market, the following actions must be undertaken:

- Raising wide-spread awareness of MMSC
- Educating consumers on the benefits of MMSC
- Openly discussing common concerns regarding straw construction, and overcoming these objections
- Providing reputable building warranties

Some consumers will be hesitant to live in MMSC homes until a large number have been constructed and lived in for years, or even decades. Regardless of this demographic, research (79) does indicate that there is sufficient confidence in, and therefore demand for, MMSC homes within the UK.

The key areas of concern identified in interviews with professionals and the public are discussed herein:

STRUCTURAL LONGEVITY

The Shambles, York - Well-maintained natural materials such as the timber shown here can last for centuries.

Source: Unsplash

Straw homes were only introduced to the UK in the 1990's, but there are examples in the USA that are over 100 years old.(56) When studying straw homes in the UK, no issues have presented themselves which indicate this method of building is substandard. Straw homes are strong enough to support roof loads, but for apprehensive homeowners who do not fully trust the structural capabilities of straw, heavy loads in MMSC homes are supported by a combination of timber and straw. Reassuringly, MMSC homes built by UK-based company Modcell have passed all necessary tests and requirements.

Research shows that the majority of the British public who are looking to buy would consider an MMSC home. The first wave of MMSC homes can be used to demonstrate their longevity, improving customer confidence for those who are initially hesitant. Additionally, consumer apprehensions can be relieved by the presence of a reputable new build warranty.

Similarly to timber, which has been utilised in construction for centuries, straw has an incredibly long life and does not biodegrade unless sufficiently damp. Countless straw homes have been built in situ which, despite being exposed to the elements during the construction phase, have no issues when built correctly by those with suitable expertise. MMSC homes enable straw panels or 'pods' (rooms) to be built and made water tight in factories, before being transported to site for assembly. The building fabric and the straw within would remain dry and retain its long life with no risk of water ingress.


Unprotected log decaying in a wood

Source: Unsplash

MMSC walls are elevated above the ground so that ground water and rainwater splashback is not able to penetrate the wall panels. Waterproof lime renders are also applied to all exteriors. Building MMSC homes in factory conditions ensures high quality construction with minimal likelihood of water ingress.

Some areas of the country, predominantly in the west of the UK, experience driving rain (rain blown with force by strong winds into external walls) and are more likely to suffer from damp as a result. This can occur in properties of varying construction types. It is therefore recommended that MMSC homes are not constructed in areas of severe driving rain, such as parts of south Wales, until sufficient testing has been undertaken. Fortunately, areas subjected to severe driving rain are predominately located in rural locations in the west of the UK, far from areas with straw surpluses and with generally lower housing demands. Ultimately, straw is no different to timber: if exposed to water with no protection, it will rot and degrade; if kept dry and maintained, it will endure and have a long life. The longevity of natural materials, such as timber, are well evidenced in many of our nation's historic buildings. There is no reason why MMSC homes would not endure for hundreds of years if designed and maintained to an appropriate standard.

FIRE RISK

For a fire to start there must be the three elements present, which are collectively referred to as the 'fire triangle'. These are: heat, fuel and oxygen. Straw bales are packed so tightly that a fire is suffocated before it can fully take hold, due to a lack of oxygen. Fire testing has shown that straw walls burn very slowly and tend to smoulder and charr at the edges, similarly to timber, rather than fully igniting.

Modcell fire tested their MMSC walls, by conducting trial, in which time their test panels had burned to between one third and one half of their original thickness in over 2 hours.(80) These results exceeded regulatory requirements. Lime render, which is applied on MMSC wall panels, was not applied in Modcell's fire test which would have provided greater fire resistance.

Straw bales have a low fire risk due to how tightly they are compacted, but loose straw - if allowed to accumulate - can pose a high fire risk. The main source of loose straw is from off-cuts from the resizing of straw bales. Appropriate measures must therefore be taken in MMSC factories to ensure that loose straw is removed efficiently and effectively.

Building MMSC homes in a factory environment enables systems, training and procedures to be enforced to create low fire risk environment. As outlined previously, should straw bales be produced in construction standardised straw balers, then fire-resistant qualities could be further improved and loose straw minimised. If consumer concerns regarding fire safety were severe-enough to deter purchasers, then further fire safety measures could be installed, such as mist or sprinkler fire suppression systems.

RODENTS AND INSECTS

Straw offers little nutrition as food and as such does not attract rodents or insects any more than other materials in this respect. Small quantities of unharvested grain can be contained in straw bales which may attract rodents (81) and some animals may seek straw for bedding or nesting. Homes must therefore be adequately sealed to prevent ingress, this is achieved with lime render. Factory construction further reduces the likelihood of rodent ingress, as panels would be sealed during manufacture. It should be noted that all homes can suffer with animal and insect habitation; traditionally-built homes have cavity walls and other crevasses in which animals can live in, but given their lack of interaction with occupants they mainly go unnoticed. Any building has the potential to be subject to animal habitation if not properly maintained.

FURTHER CONSIDERATIONS FOR MMSC AND STRAW-BALE CONSTRUCTION

MMSC homes are far lighter in weight than traditionally constructed buildings and many other MMC alternatives; many of which incorporate heavier materials such as concrete and steel. A building's foundations must support the building's load, with foundations typically being constructed of concrete. The greater a building's weight, the more substantial the foundations required.

As MMSC buildings are light-weight, their foundations are minimal. This means less concrete is required, therefore reducing environmental impacts and further lowering costs due to lower material demands and labour requirements. These savings can be then passed onto homeowners to improve affordability. UK-based business Straw Works have found that the loads of straw buildings are so light that they have utilised car tires filled with earth as foundations, as opposed to concrete. With further testing and conclusive evidence, this could be incorporated into large-scale MMSC designs, lowering costs and making use of car tires which are notoriously difficult to recycle.

Mortgagees issue their own lending policies, these include guidelines for lending on common property types. For lesser known forms of construction such as

individual types of MMC including MMSC, lenders often refer to surveyors to make decisions – surveyors in turn are often largely influenced in their decision making by the presence of a suitable new build warranty. This is discussed further in Section 3.

As a building material, straw offers many benefits to the UK. The negatives of its use mainly revolve around a lack of awareness, expertise and established supply chains. These issues will be overcome when MMSC becomes more mainstream. Straw is readily abundant and available at low cost in the UK. It is a proven building material; some more conservative professionals may argue that straw homes have not been present in the UK for long-enough to prove their longevity, but all testing and case studies have thus far demonstrated the opposite. This is further evidenced by long-standing examples of load-bearing straw homes overseas.

As outlined previously, UK housebuilders are overly cautious in many respects and slow to change of their own accord. Drastic action is required to implement MMSC as soon as possible in order to combat the time sensitive crises the UK is facing.

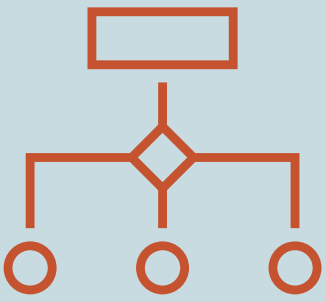
SECTION CONCLUSION

MMSC has huge environmental and economic potential for the UK. This construction method, if implemented on a sufficiently large-scale, has the potential to meet national housing and environmental needs by utilising low-cost, environmentally-friendly, predominantly UK-sourced construction materials. Large-scale MMSC production has the potential to lower housing costs, improve the financial sustainability of farmers and provide employment opportunities for a range of workers, including those without higher education.

A number of government aspirations can be met if MMSC is sufficiently funded and supported, including the 'building back greener' and 'levelling-up' initiatives, and reaching net zero emissions by 2050.

SECTION 3

IMPLEMENTATION



INTRODUCTION

This section lays out avenues for the implementing and incentivising of MMSC construction on a large scale, so that it can provide the maximum environmental, social and economic benefits to the nation. Issues that were outlined in Section 1 but not overcome in Section 2 are discussed herein. The implementation section aims to ensure MMSC homes are not only built in large numbers, but also to a high-standard and in a short space of time.

It is the view of this report that MMSC homes should supplant traditionally-built homes as the new, long-term construction norm for the UK.

If implemented effectively, MMSC homes could not only satisfy current housing demands, but they could also replace poorly-built existing homes. Millions of Victorian and early 20th century terraces remain in use today. Many homes from this era were built for factory workers, particularly in the North of England. These homes are densely packed, typically having no car parking spaces or garages and limited outdoor space. Typically, they also have poor energy efficiency and are often more susceptible to dampness, which can cause health problems for occupants.

Although these homes served a purpose when constructed over 100 years ago, they are no longer suited for modern life and the needs of the British public. Replacing these homes with spacious, well-insulated houses, designed to complement modern lifestyles, would have substantial benefits; reducing household expenditure while improving the health and quality of life of occupants. Historically, periods of 'slum clearance' have been implemented, whereby substandard housing was subject to large-scale demolition programs to make way for modern homes.

This has not been undertaken in recent decades as the demand for housing has been too great. This has led to outdated, inefficient homes remaining occupied beyond their anticipated lifespan. Presently, 23% of all privately-owned homes in England were built before 1920.(82) While not all of these homes are of poor quality many are, particularly in towns and cities.

MMSC HOMES – WHO WILL BUILD THEM?

As previously noted, MMC homes require a large amount of upfront capital. Early costs include that of research and development, factory sites, machinery, staff training and more. Furthermore, in order to lower costs, a MMSC company should also be a developer and not outsource factory construction to other organisations. Removing a third-party developer ensures a regular output of homes and reduces the number of house types being built, decreasing build costs and improving build quantities and quality.

For this to be achieved, an organisation must have a suitable land bank or the funds and expertise to acquire one (the term 'land bank' refers to the ownership of land by a company in readiness to be built upon) along with funds to establish the MMSC factory itself. These factors, particularly in regards to having sufficient capital, significantly limit the number of businesses and organisations which can realise mass MMSC production.

Below, the capability of candidate organisations to construct a large number of MMSC homes is considered:

EXISTING HOUSEBUILDERS

Existing traditional housebuilders are not plausible MMSC manufacturers for the reasons outlined in Section 1. In brief, they are too risk averse and because they are already making significant profits, they see MMSC as an unnecessarily risky investment. This is evidenced by the limited uptake of MMC by existing large-scale housebuilders to date. Crucially, these businesses are driven by financial success, and not by social or environmental consciousness.

Although MMSC may be adopted by large-scale housebuilders once the method of building becomes commonplace, they are not the vanguard required to stimulate this change.

NEW ENTRANTS TO THE MARKET

A new private-sector entrant is unlikely to have the capital, expertise or land bank to instigate MMSC on a large-scale. Ultimately, given the factory-produced nature of MMSC, only large-scale production would be cost-effective and able to achieve the environmental and social objectives required by the UK in a timely manner. This is evidenced by the aforementioned, Bristol-based builder, Modcell. Their limited funding did not enable them to create a permanent MMSC factory with a complement of full-time staff, instead using temporary factories and subcontracted labour. As a result, Modcell has not produced a large number of homes and those which have been produced have been commissioned by more climate-conscious clients.

The government provides grant funding and loans for MMC companies in order to increase housebuilding capacity and create greater competition and innovation in housebuilding, diversifying the number of major housebuilders. In order for a new private-sector market entrant to succeed in producing a large number of MMSC homes, they would require a substantial proportion of their funding to come from government subsidies and loans.

The requirement for a company to make profits for the business owners would further increase the build costs associated with MMSC homes, making the solution less able to alleviate soaring property prices. Furthermore, investing large sums of public funds into a private company may be viewed by many as inappropriate and not in the public interest. Ultimately, new market entrants are unlikely to succeed in creating the quantity of affordable MMSC homes required to satisfy housing demands.

LOCAL AUTHORITIES

As shown in Figure 17, local authorities have previously played a major role in meeting the UK's housing needs. At the nation's housebuilding peak in the late 1960's, approximately 43% of new homes were built by local authorities:

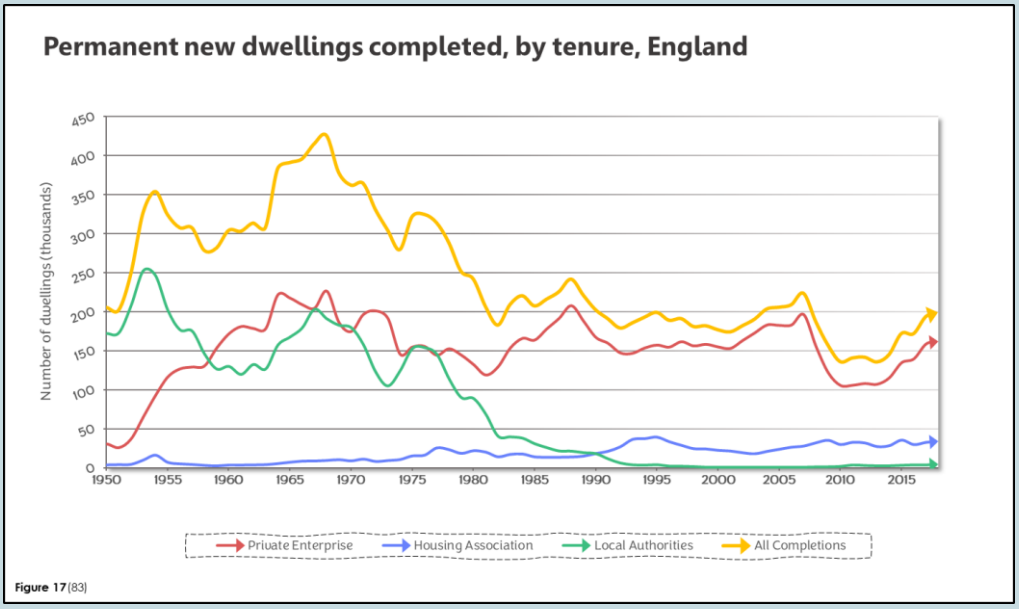


Figure 17 (83)

It is unlikely that a single local authority will have sufficient demand for MMSC homes to produce them at a cost-effective scale. An effective solution could be a collaborative effort between local authorities. To ensure high demand and cost-effective, large-scale production, an organisation could be created by several local authorities to provide homes to a number of local councils. The nature of councils unfortunately means that collaboration could be complicated and slow.

Ultimately, decision-making regarding design and production may be disjointed, and differing viewpoints from authorities would increase the risk of a project failing to achieve its aims. Furthermore, the historic expertise of councils regarding the construction of large-scale housing projects has been lost over the past thirty years, as their role in housebuilding has declined.

A further benefit of local authorities building MMSC homes is their large land banks, with land readily available for construction, lowering their cost of entry to the market.

HOUSING ASSOCIATIONS

Since the decline of council house construction, housing associations have been fulfilling some of the roles previously filled by local councils; this rise in prevalence is shown in Figure 17. Housing associations are non-profit organisations which provide low-cost accommodation to those with low incomes or particular needs. Unlike local councils and private housebuilders, housing associations do not typically have large land banks and would therefore have to purchase land to branch into MMSC construction, increasing upfront costs. Given their limited portfolio-generated income and limited capacity to raise funds, the start-up costs of MMSC production would be problematic and would likely require government subsidies.

On a positive note, many housing associations construct their own developments and therefore have existing construction expertise which could be expanded upon.

SUMMARY OF EXISTING OPTIONS

Table 3 summarises the key points relating to existing organisations and their capability to construct a large number of MMSC homes:

Table 3: Comparison of organisation's capacity to construct a large number of MMSC homes

Organisation	Established Expertise	Capital	Land Bank	Profit-driven	Socially driven
Existing Housebuilders	Yes	Yes	Yes	Yes	No
New Private-sector market entrants	No	No	No	Yes	No
Local Authorities	No	Yes	Yes	No	Yes
Housing Associations	Yes	No	No	No	Yes

Given their lack of social drive, existing housebuilders and new private-sector market entrants are unlikely to build MMSC homes at a sufficient scale to solve the UK's housing needs. Any profit-driven organisation will inflate the cost of new MMSC homes, exacerbating the affordability aspect of the housing crisis. Substantial government incentives would be required

for the private-sector to be the first to produce large-scale MMSC homes, and ultimately their aspirations would not align with those of the state.

Both local authorities and housing associations are driven by social aspirations, as opposed to financial aspirations, which is highly beneficial when creating MMSC homes. This is because MMSC homes will be significantly less profitable than traditional homes for several years, until production is optimised.

HOUSING MARKET DISRUPTER

PUBLICLY-FUNDED AND NON-PROFIT

For MMSC to become the dominant residential method of construction in the UK, particularly in the urgent timeframe required to combat the housing and climate crises, private sector funding must be employed. Doing so will create competition, drive innovation and relieve pressure on public finances. The private sector will not invest in MMSC until it is already an established and successful method of construction. In order to unlock private sector investment, this review proposes that a 'market disrupter' is created. This organisation would serve as a catalyst, competing with established housebuilders and forcing them, by way of natural market competition, to operate in a way which is more aligned with the social and environmental aims of the nation.

Example of Market Disrupters Causing Industry-wide Change

Estate agents in the UK were traditionally located on Britain's high streets. Since the early 2010's however, 'online' and 'hybrid' estate agents have entered the market with new business models. These companies were thought by some to be the future of estate agency, and the 'new norm' when compared with the business models of traditional high street estate agents. Some predicated that online estate agents would increase their market share to as much as 50%.(84) As of 2022 however, online estate agents only account for 7% of all properties sold in the UK.(30)

Although the online estate agency model has not supplanted that of the traditional high street agents, these new estate agencies have caused significant change to the industry as a whole. As traditional 'high-street' agents witnessed the rise of this new threat, they have adapted and amended their working practices. Some common changes include opening for extended hours for the convenience of their customers, and offering a new variety of pricing strategies. Over the past decade, new market entrants have been the catalyst to change in the estate agency sector.

To force British housebuilders to adapt to the ever-changing landscape of the 21st century, a similar scenario must be manufactured. A new market entrant is unlikely to supplant well-established, existing housebuilders, but a new market threat could spur great change in what has been a slow-changing industry. One well-planned organisation could cause a change in the industry, aligning it more closely to national environmental and social aims, reducing the funding required to achieve these objectives and increasing the rate of change.

The solution with the greatest potential for making MMSC the new norm in residential construction is to create a new, non-profit, government funded organisation. Such an organisation would utilise publicly owned land, such as that controlled by Homes England, to construct a new generation of homes for the UK. By creating a new, independent organisation, this removes any bureaucracy and communication issues which could occur should several local authorities collaborate. While this new organisation will have social and environmental aims aligned with those of the government, it should be given sufficient autonomy to act independently. It should also have minimal restrictions and the ability to adapt and change in a similar fashion to private sector businesses.

Example of Improving Housing Standards

Significant improvements to the quality of private sector housing following the end of World War I are largely accredited to the rise in local authority housing. The drive to build spacious, high-quality, social housing set high standards for private housebuilders. Their public image, and therefore their profit margins, would be damaged if they did not begin to construct homes which were of a higher quality than the new social housing being built. This led to a drastic improvement in both public and private sector housing over a short space of time.

MMSC production costs will reduce as production is scaled up however initial costs will be relatively high until production is optimised.

Until production is optimised and at full capacity, this new organisation may create homes which are more expensive to construct than that of equivalent, traditionally-built homes. Private-sector housebuilders typically have operating profits of approximately 20%. Because this public enterprise will not be profit driven, it can utilise what would have otherwise been profits to offset higher build costs, selling homes at a similar price to traditionally-built homes. Alternatively this margin could be split, spending a portion of this margin on the rapid expansion of MMSC, to hasten optimisation and price cuts, with the remainder offsetting higher initial build costs.

The organisation's alignment with government interests could also mean that standard housing designs include other features, such as rainwater and greywater harvesting, and car charging points. At present, these additions are not typically included in new homes unless required under local planning policy, as developers seek to minimise build costs and maximise profits.

As outlined in the aforementioned text headed '*Example of Improving Housing Standards*', including features such as these at no additional cost to purchasers would set new expectations for housing quality and drive up housing standards in the private sector. According to the Committee on Climate Change, environmentally conscious housing features cost as little as 1-4% of total build costs, meaning such additions could feasibly be fronted by both MMSC and traditional housebuilders.(85)

The concept name for this new, publicly-funded organisation is *Strawmill Homes*. This name is used throughout the rest of this paper to refer to this proposal.

STRAWMILL HOMES

Implementing a government funded and supported, non-profit organisation is deemed to be the most effective way of creating a large number of MMSC homes in the UK. This organisation would have several benefits:

- **A social and environmental objective**, driven by national objectives to build high-quality housing.
- **Reduced build and sale costs,** as a result of mass construction and use of straw as a low-cost building material.
- **An available land back;** Homes England could be used to supply the organisation with land at low or nil cost. This would improve build certainty and lower costs.
- **Access to sufficient funding** to enable this project by providing capital for research and development as well as start-up costs.
- **As a separate organisation**, Strawmill Homes can act flexibly, react quickly to changes, expedite research and development and exist outside of the slow-moving bureaucracy of existing public bodies.

With additional government support as outlined below, the use of MMSC would greatly increase the volume of social housing, while also improving affordability for the nation's residents:

MITIGATION OF DEVELOPER CASH FLOW RISK AND UTILISING LOCAL AUTHORITY LAND BANKS

As previously displayed, local councils provided large quantities of social housing until the 1980's, but they have since lost their construction expertise. Local authorities still own large areas of land, many of which are suitable for development; currently, these plots are being sold to the highest bidders. All start-up housebuilders, including Strawmill Homes, face potential cashflow problems as large sums of money are required, particularly in their infancy. Large funds are required to develop the business and purchase land on which new homes are to be constructed. Strawmill Homes' cash flow risk and the ongoing council house shortage can be mitigated by encouraging cooperation between Strawmill Homes and local authorities to create a joint solution.

It is proposed that legislation is passed to allow Strawmill Homes to have the first refusal to purchase council-owned land. The price of the acquisition would be agreed between both parties, with both organisations undertaking an appraisal. An independent third-party would mediate if both parties cannot agree on the purchase price. This method of land appraisal and purchase is well established and commonplace. This legislation will also provide Strawmill Homes the power to dictate to local authorities how the land will be paid for, with the following payment options:

OPTION 1 – CASH ONLY PURCHASE

Development land is purchased in cash, with a reasonable element of deferred payments if required, as is typical in land acquisition for large development sites.

OPTION 2 – PROVISION OF COUNCIL HOUSES

Strawmill Homes can be given the power to purchase local authority-owned land by gifting the local authority a portion of the new homes built on the land as a means of payment. These

homes would be transferred to the council's ownership and must be utilised by the local authority as new council houses. The homes will be valued at market value, and the number and value of homes should be equivalent to the agreed purchase price for the land. The new council houses would be transferred to the council once they are completed and fit for habitation.

This means of land payment has numerous benefits for both parties:

BENEFITS FOR STRAWMILL HOMES:

- Cashflow for Strawmill Homes would be improved as no large upfront payments are required.

BENEFITS FOR LOCAL AUTHORITIES:

- Local authorities obtain much needed, newly-built council houses.
- Council houses are newly-built and are therefore low-maintenance, reducing the council's expenditure to upkeep these dwellings.
- Councils obtain new council houses without the need to find the funds and expertise to build them.
- New homes are environmentally-friendly, well-insulated and include renewable energy and water conservation fixtures (PV panels, rainwater harvesting, etc.), amounting to low running costs. This means that occupants of council homes have low expenditure and benefit from improved financial security.

OTHER BENEFITS:

- Planning authorities require developers sell a predetermined number of their homes on new developments to a public housing organisation, be it the local authority or a housing association. This is enforced as a condition of obtaining planning permission. For example, local authorities may specify that 25% of all new homes on a given development must be designated as affordable social housing. Housing associations and on occasion, the local authority, make sealed bid (informal tender) offers to purchase these affordable social homes. This creates a competitive environment where various non-profit, government funded organisations attempt to outbid one another, increasing the cost of these homes.

  If Strawmill Homes exclusively builds and supplies local authorities with council houses on formerly-council-owned land, competition is removed, reducing council house acquisition costs for local authorities. Reducing the purchase price of public housing frees up funding to create more public housing. It should also be noted that some councils have attempted to limit competition social housing providers by capping affordable housing purchase prices, but loop holes persist that render these countermeasures ineffective.

When this legislation is enacted, it would lead to a new generation of council homes, built at low cost and independently of local authorities, who do not have the expertise or resources to achieve such an undertaking. This scenario avoids the need for collaboration between local authorities, while enabling a large number of low-cost council houses to be built to a high standard, across numerous local authority areas. Strawmill Homes' improved cashflow will also hasten the organisation's expansion to more quickly arrive at efficient, low cost manufacturing.

OPTION 3 – HYBRID

A hybrid of Options 1 and 2 is also a viable payment strategy, whereby part of the payment is made in cash and the remainder is paid by the transfer of new social housing. To retain autonomy, the proportions of each will be determined by Strawmill Homes.

PLANNING POLICY AND HOUSE TYPES

The term 'house types' refers to the different housing designs which are created by housebuilders. Large housebuilders construct the same house types across the nation with little to no regional differentiation. This approach reduces design and build costs, improves build quality and increases output. It is proposed that Strawmill Homes should have a minimal range of house types to maximise these benefits, while still ensuring a sufficiently broad range of house types to offer some variety in accommodation.

Housing in previous decades has been criticised for using too few house types. This resulted in a lack of aesthetic variety and created estates that have been described as 'devoid of character'. Repetitive house designs are less obvious on modern estates, as current planning polices advocate for house types to be dispersed throughout a development. Attractive developments can still be created with few house types by using symmetry in design; this approach would be well-suited to Strawmill Homes.

Repetitive historic housing designs:

Source: Wikipedia

Source: Google

Modern use of symmetry in housing developments:

Interspersing a small number of house types on a development opposite their mirror image can create housing variety and a varied street scene. This approach could be replicated by Strawmill Homes.

Symmetry used to great effect on a modern housing estate to create an attractive street-scene

In the UK, local planning authorities are consulted when new build developments are proposed; planning permission is required before construction can commence. Local authorities have a large degree of autonomy regarding housing design. Each authority creates its own planning policy outlining its requirements and preferences. Unfortunately, these policies vary widely between authorities.

Differences in planning policy can require neighbouring estates to have different house types if they are separated by jurisdiction, even when they are constructed by the same housebuilder. For housebuilders, this creates inefficiencies as houses have to be adapted to suit local authorities. This is particularly troublesome for optimised MMSC construction, which relies on standardisation to increase affordability. Furthermore, local planning polices are often worded ambiguously, with local councillors occasionally making requests of developers based on their personal preference or opinion. This can cause delays and increase build costs.

Strawmill Homes could maximise its build quality, construction rates and affordability by embracing as much standardisation as possible. Perfecting a concise range of house types which meet the needs of the people is a key aim. Adapting each house type to local planning policy, or to the whims of local councillors, is counterproductive to the aims and opportunities offered by Strawmill Homes; particularly the aim of producing a large number of homes in a short timeframe. It is therefore proposed that as part of Strawmill Homes' special status, the organisation's house types - and to a lesser degree, its development layouts - should not need to conform to local planning policy.

Instead, Strawmill Homes should design a set range of house types in line with national policies and guidelines, such as housing space standards which dictates minimum rooms sizes. This would greatly improve the production and quality of MMSC homes, while significantly reducing build costs. Furthermore, it would greatly expedite the planning stage of developments, meaning construction can

begin much sooner. It is recommended that this exception should not apply in geographical areas with special planning designations such as National Parks, Areas of Outstanding Natural Beauty (AONB) and conservation areas. This however should be of little concern as it is envisaged that Strawmill Homes would aim to build large numbers of homes in non-sensitive areas, with the aim of solving the housing crisis.

BUSINESS STRATEGY

As previously discussed, Strawmill Homes' supply of land would be largely provided by Homes England and other public organisations, such as local councils. Further land could be acquired privately, in a similar fashion to that of traditional housebuilders. The build cost of MMSC homes may be greater than that of traditional homes initially until supply chains are well-established and outputs are increased. Once a substantial volume of MMSC homes are constructed, development costs will subside and private sector housebuilders will be reassured that they can follow suit with limited financial risk. As more developers adopt MMSC, a greater reduction in build costs will be observed, and this cycle of cost efficiency shall continue until MMSC is the dominant residential construction method in the UK.

In order to combat climate change and the housing crisis simultaneously, MMSC homes must be built to a high standard and a comparable price to that of traditional homes. It is envisaged that in order to achieve these objectives, Strawmill Homes should function similarly to private sector housebuilders. Despite its social aims, the organisation should not build developments comprising only of social housing, as was undertaken by local authorities in previous decades. This approach limits diversity on these estates and creates social division. Furthermore, this would significantly reduce revenues and result in a slow rate of organisational growth, unless further public funds are injected.

Strawmill Homes should instead build the maximum possible number of private homes on its developments, building only the number of affordable homes specified in local planning policy - with the exception of any homes to be transferred to the local council in lieu of cash land payments as proposed previously. This will maximise income to aid in rapid expansion by generating revenue from private house sales, which can then be reinvested into the business with no additional cost to the state.

Although rapid expansion would be a key aim of Strawmill Homes, the organisation must ensure that homes are built with the best interest of the public in mind, and in such as a way as to drive innovation in housing standards. This could be achieved by designing 'ideal' house types from the outset, such as homes which include PV panels, rainwater harvesting and electric vehicle charging points as standard. It would then have to be ensured that these key design principles are not compromised. Many established housebuilders reduce the specification of their new build homes to reduce build costs and therefore increase profit margins or land purchase prices. As a non-profit enterprise, Strawmill Homes can ensure that it does not compromise its aims for profit.

In the long-term, once sufficient expansion has been undertaken to incentivise large-scale, private-sector investment in MMSC, Strawmill Homes' role will change. The organisation can continue with its aim of improving housing standards by way of market disruption and competition. Alternately, Strawmill Homes could adjust its role to focus on creating public housing. Ultimately, Strawmill Homes' long-term role

can be reviewed once the current crises are averted and its initial aims are achieved.

Many public organisations require ongoing taxation to enable their continued existence; this is the case for the NHS, schools and policing. Strawmill Homes would be unlike many other public organisations, in that once initial funding is provided to enable its creation and establishment, it will become self-sustaining with no further public funds required. Profits made from the sale of homes on the open market can be reinvested into further expansion.

LOCATION

Straw has a low value to volume ratio, making it expensive to transport over long distances. As discussed in Section 2, there are several areas of true straw surplus in the UK: Yorkshire and the Humber, the East Midlands and the East and South-East of England. North Lincolnshire would be a preferential location for an initial MMSC factory, despite East Anglia producing a greater straw surplus; full reasoning for this is detailed within this section.

Figure 18: Straw bale transportation
Source: N.R. Marsden Agricultural Contracting

Major influencing factors are that North Lincolnshire's location is more central within the UK with connections to nearby major ports and national motorway networks. These connections are essential for the provision of raw materials to the site and distribution of MMSC components nationwide. East Anglia, for example lacks major networks, with roads too narrow for the regular transportation of wide-load MMSC lorries.

Lincolnshire and Yorkshire produce large surpluses of straw (see Figure 13 on page 50). Furthermore, many towns in this area have high rates of unemployment, particularly in North Lincolnshire. Figure 19 below shows a map of this area with key areas of note highlighted.

Figure 19: Map of area of high straw surpluses in England

A significant proportion of Scunthorpe's population was historically employed in the local steel works, an industry that has been in steady decline over recent years. Grimsby, located approximately 23 miles east of Scunthorpe, was traditionally a large fishing hub; like steel works, this industry is also a shadow of its former self. The reliance on large employers has led to high levels of poverty and unemployment in both towns; as these industries declined, new employment opportunities have not met the needs of local people.

Furthermore, the locations of these settlements are far from prosperous towns and cities, where employment opportunities are greater. Many inhabitants of these settlements are without higher education, though there is an abundance of machine operators, manufacturers, construction workers and transport workers, who are all well-suited for roles in MMSC.

Reviewing the map in Figure 19 and statics in Table 4, it is logical that a new MMSC factory should be located in Scunthorpe. The town has the benefit of being close to high straw yield areas in Lincolnshire and Yorkshire, with easy road access to the M180 and the large ports located at Grimsby, Immingham, Hull and Goole. The nearby ports of Grimsby and Immingham combined are the second largest in the UK in terms of tonnage imported after London.(87) These major ports are conveniently located for the import of timber from Scandinavia, Germany and the Baltic states, a key component of MMSC houses. Timber must be imported for the foreseeable future, until a time when sustainable domestic sources are established; this however will unfortunately take decades to be realised. The short distance from these ports to Scunthorpe also mitigates the impact of the ongoing lorry driver shortage.

Scunthorpe's central location to other areas of high unemployment, such as Grimsby, Doncaster and Hull, will provide an employment boost to the regional economy. Higher education rates in these areas are lower than average, so employment in MMSC will suit the education level of the local residents.

Furthermore, there is a higher than average percentage of the local population employed in construction, transportation and manufacturing, providing a promising indication of strong skillsets within the locality, which will enable MMSC to thrive.

Locating a factory in Scunthorpe will play to local strengths by utilising established infrastructure and the available, appropriately skilled workforce. This location also coincides with the government's ongoing aspirations to create a 'northern powerhouse' in northern England and 'level up' the populace as a whole.

Table 4: Key regional settlement statistics, 2020 (86)

Settlement	Statistics Area (NOMIS)	Population	Unemployed		Employees working as Process plant and machine operatives	Population with NVQ Level 4 and above (%)	Gross weekly pay / week (£)	Population employed in Construction	Population employed in Manufacturing	Population employed in Transport and Storage
			Number	Percentage Unemployed						
Scunthorpe	North Lincolnshire	172,700	3,800	4.8%	8.4%	32.4	525	8.1%	23.0%	8.1%
Grimsby	North East Lincolnshire	159,400	3,600	5.0%	13.8%	25.5	555	4.5%	16.7%	7.6%
Doncaster	Doncaster	312,800	7,800	5.4%	10.2%	26.2	564	7.4%	9.1%	9.1%
Hull	Kingston Upon Hull	259,100	7,600	5.8%	11.1%	23.0	484	5.7%	16.3%	4.1%
	Yorkshire and the Humber	5,526,400		5.1%	7.0%	23.7	540	5.4%	11.4%	5.1%
	Great Britain	65,185,700		5.0%	5.6%	43.1	587	4.9%	8.0%	4.9%

WORKFORCE

As outlined in Section 1, it is essential to incentivise people to join and remain working in the residential construction sector. Steps must be taken to make employment more appealing, while also attracting a wider demographic of employees. How MMSC will achieve this was discussed in Section 2, with further detail relating specifically to Strawmill Homes' discussed below.

The workforce for Strawmill Homes will be hired from these main sources:

- **Local workers, who are unemployed or in low-salary positions -** Local workers will be hired from Scunthorpe, Grimsby, Doncaster, Hull and other commutable areas. MMSC factory work will present an opportunity for locals to enter into - and progress in - a cutting edge and environmentally sustainable line of work; this will be particularly appealing to individuals who are unemployed, earning low salaries or working in roles with limited career progression. Doncaster and Hull in particular have significantly higher than average rates of unemployment at both regional and national levels.(88)
- **Workers with valuable skillsets** - As shown in Table 4, the rates of those working in machining, manufacturing, construction and transport are higher than average in the Scunthorpe area. Logistical expertise will be essential when transporting the manufactured homes to their destinations for onsite assembly along with other tasks, such as transporting straw and timber.

  Yorkshire is already home to a relatively high number of MMC home manufacturers, including Ilke Homes in Knaresborough and Legal and General in Leeds. Experienced staff can be hired from these businesses to assist in training and the dissemination of information, helping to establish Strawmill Homes quickly and effectively.
- **Veterans –** Contrary to common belief, not all veterans have reached retirement age. A growing number of military personnel are also leaving the armed forces at a younger age than in previous decades.(89) A number of schemes are already in place to help veterans transition from life in the armed forces to employment in construction. Schemes are offered by Persimmon Homes and Wilmot Dixon, which are tailored specifically to veterans. Practical work can be appealing to veterans, as it is more relatable to their previous work when compared with desk-based employment. There

is a growing trend in workplaces for both the location of work and working hours to become more flexible.

Due to the nature of construction work however, set working hours are likely to be required for the foreseeable future. Construction's lack of flexible employment may be a detriment to many potential employees, but certain demographics, such as ex-service personnel, are used to regimented work schedules. Those previously employed in the armed forces are likely to find employment at Strawmill Homes more appealing and rewarding than many other occupations, given these factors.

Approximately 15,000 veterans leave the armed forces each year.(89) Employing from this talent pool offers a 'win-win' opportunity for both veterans and Strawmill Homes. The discipline, training and leadership skills of ex-military personnel will complement the organisation and diversify the workforce from those recruited locally. A strong work ethic will make them good role models for formerly unemployed individuals who may require time to adapt to working life. Likewise, locally-sourced employees can assist veterans in adapting to civilian life.

As discussed below, on-site employee housing would also be a great benefit to ex-armed forces employees as Strawmill Homes could offer a lifestyle more akin to that which they are accustomed.

STRAWMILL HOMES MMSC FACTORY

CASE STUDY – SALTAIRE

Located in West Yorkshire, the village of Saltaire is a world heritage site which takes its name from Sir Titus Salt, a 19th century mill owner and philanthropist. Salt established a textile mill, known as Salts Mill and constructed housing for his employees in the vicinity of the mill. Unlike other homes built at the time, Salt's homes were well-planned and built to a high standard with amenities constructed nearby. Implementing a similar approach for Strawmill Homes will have numerous benefits.

STRAWMILL HOMES – FACTORY LOCATION AND CONFIGURATION

As previously outlined, a logical location for Strawmill Homes' initial MMSC factory is Scunthorpe, north Lincolnshire. There are very few straw and MMSC-built homes in the UK, or even globally, therefore there are currently very few experts. The number of those with expertise in any form of MMC construction in the UK is also low although Yorkshire is a national hub for MMC construction. MMC workers can be sourced from the Yorkshire-based housebuilders of Legal and General and Ilke Homes, with other employees being recruited from manufacturing and construction sectors.

It is proposed that the Strawmill Homes' MMSC factory should be created similarly to a Tesla 'Gigafactory', whereby as much of the assembly process as possible is under one roof. This has numerous benefits, including reducing build costs, transport times and construction times, while simultaneously improving build quality and improving skillsets, as employees better understand the overall build process and their role within it by way of exposure. Office-based staff should be located at the same site as the factory, encouraging greater integration and improved dissemination of knowledge, therefore improving build quality.

It is proposed that as well as constructing a purpose-built factory, housing for employees of the company should also be

constructed adjacent to the factory for the workers, akin to Sir Titus Salt's social endeavours at Saltaire. Building homes for the workers creates numerous benefits:

Improved build quality - Even when best efforts are made to perfect a product, defects and issues do still can occur, and housing is no different. Given the infancy of MMSC, and that almost the entire workforce will have to be trained in straw construction from scratch, issues relating to MMSC may be more prevalent during the enterprise's infancy. MMSC homes must be of excellent design and built quality before they are occupied by the public. Any poor publicity relating to MMSC homes could be detrimental to public confidence, resulting in disastrous long-term effects, as seen with the timber homes of the 1980's.(90) Bad publicity could see MMSC construction delayed by decades or even indefinitely. This cannot be allowed to happen if the UK's housing and environmental crises are to be overcome. Constructing MMSC homes adjacent to the factory means that any teething issues can be identified and resolved quickly, effectively and most importantly, before members of the public begin to purchase straw homes elsewhere in the country. Building next to the factory also enables employees to see straw homes being constructed, furthering their understanding of the process and increasing employee's commitment to the organisation's goal.

Data collection – In order to perfect MMSC homes, it would be highly beneficial to collect data on their performance. Prototypes can be created, but these can never fully emulate an occupied dwelling. Employees will be incentivised to rent on-site MMSC housing by offering tenancies at below typical market rental values. On-site housing will also reduce employee's commuting time and costs, therefore improving work-life balance and increasing disposable income. Commuter traffic is also a major source of stress, so eliminating the commute will also help to keep workplace relations copacetic and the workforce healthy; stress is, after all, a major cofactor to many occupational illnesses.(91) In return, occupants must agree to have data collected regarding their housing use and occupancy satisfaction. This would include energy and water usage. Data will be interpreted, enabling Strawmill Homes to continually asses where heat is being lost and how improvements can be made to make homes more efficient and environmentally-friendly. Furthermore, valuable anecdotal experiences of employees can be quickly and effectively relayed to design teams to improve the homes; this could include minor design changes, such as changing the location of plug sockets and light switches. Once on-site housing is constructed and trialled, the house types offered by Strawmill Homes will be ready to present to the public, with little concern over bad publicity arising from manufacturing errors. Purchasers can also be informed of accurate energy efficiency costs and the environmental benefits of MMSC homes, so that they can make informed decisions regarding their purchase.

Environmental ethos – Reducing emissions and congestion with less commuting aligns with the organisation's ethos, while improving the appeal of the workplace to employees who wish to work for an environmentally conscious employer. Such employees may also be interested in trialling straw homes for the sake of the planet's future.

Inclusivity – As employees living on site do not require to drive to work this creates more inclusive employment opportunities.

Consumer confidence – Many large housebuilders offer discounts to employees who purchase one of their employer's homes. At first glance, this seems solely beneficial for the employee given the discounted property price. On closer

inspection however, employees who purchase their employer's homes are typically required to remain employed with said employer for a minimum of five years. Should the employee leave the business during this period, they are required to repay the discounted amount.

It is of greater importance to Strawmill Homes that employees, regardless of their role at the business, act as MMSC ambassadors. Employees who live in a home built by their employer can talk confidently to friends, family, other industry professionals and the general public about the quality and reduced expenses of their new homes. As employees will have the option to rent MMSC homes, the financial commitment to their employer is far less than that of an outright purchase. Renting will also help prospective residents to overcome the apprehensions of living in a novel and non-traditional type of house. Strawmill Homes employees who trial straw homes will also have a deeper understanding of the construction methods and the quality of the build, opening them to careers opportunities in the marketing and sales department of the enterprise, regardless of their starting role. Ultimately, this means that Strawmill Homes' employees can put to ease any concerns the public may have regarding MMSC.

Flexibility – Although flexibility in construction and factory work is limited due to the nature of the work, by living on-site, employees have the flexibility to go home for lunch or undertake other personal errands, such as taking children to school, with greater ease. This will improve employees' personal and family lives, reducing stress and making a lifestyle which is appealing to prospective employees.

Apprentices – The need to attract new workers and diversify employee demographics in construction has already been highlighted in Section 1 of this review. Young people must see construction and MMSC as a compelling career, rivalling alternative sectors and education opportunities. Education can be offered to Strawmill Homes' employees in the form of apprenticeships and part-time university degrees. Many large housebuilders already offer these opportunities.

Those undertaking sponsored university degrees are typically permitted day release for university. Grants are provided to employers to assist with the cost of paying their employees through university. These are 'win-win' situations for both parties; employees do not take on university debt, earn a wage and obtain a degree and work experience simultaneously. Employers benefit from having well-trained staff who are tied into their employment at the company for several years following the completion of their course, as a condition of their training contract.

Building relationships with local universities and colleges will also provide opportunities for apprentices and other members of staff to undertake distance learning and learning on day release. The creation of Strawmill Homes in the Humber region, where large-scale training and retraining is required, is an excellent opportunity to make the most of the governments new 'T-Levels'. T-levels are A-Level equivalent qualifications which focus on vocational courses; ideal for housebuilding and Strawmill Homes. A similar approach has already been taken by MMC builder Ilke homes.(92)

Unfortunately, there is one aspect of university life is lacking from the construction industry and most apprenticeship roles; the social element of university. University allows young people to live away from home with others their own age, where they can develop as individuals and gain a greater degree of independence. To compensate for this loss in social experience, larger homes can be

constructed near the MMSC factory to accommodate apprentices in house shares. This option will free apprentices from large expenses such as travel, rent or vehicle costs, while allowing them to benefit from a similar social life to university. In this instance young people can also support each other through their training and enjoy an active social life with others their own age.

Military – Ex-military personnel can sometimes struggle to re-adjust to civilian life. Many join the armed forces at a young age, and have lived most of their adult life in the military. In the military, elements of everyday, such as healthcare and accommodation are provided through the service. In addition, many veterans who have lived in military accommodation struggle with financial skills, as outgoings are generally lower than that of civilians and a large proportion of their wages is disposable income while serving. There is a prevalence for veterans to have limited savings upon leaving the military.

"*Too many leave the Armed Forces unprepared for civilian life. They often have no savings, lack essential life skills and have unrealistic expectations*" **- SSAFA**.(89)

For veterans, living and working at Strawmill Homes will be more akin to their military life than the vast majority of other opportunities. This arrangement will help smooth the transition for ex-military personnel, while helping to support them financially via the same avenues discussed previously in this chapter. Appealing to a large number of veterans will also help to create a support network of veterans, who can empathise and assist one another during their transition to civilian life. Like apprentices, those with few savings who have departed the military will find living costs to be affordable. As Strawmill Homes is doing good for the nation it is likely to appeal to veterans and provide a sense of job satisfaction.

Research undertaken by the armed forces charity SSAFA states that 80% of veterans who have approached them for help have long-term mental or physical health problems.(89) By living in on-site accommodation and undertaking relatable hands-on work, the stress of some veterans will be alleviated. Furthermore, for those with physical disabilities, living within close proximately to work will be beneficial with those unable to undertake manual work having opportunities at the on-site offices. SSAFA also notes that there is a lack of understanding of army qualifications and their non-military equivalents. Of the veterans surveyed by SSAFA, 18% sought additional employment support and 25% sought housing support. Of veterans who contact SSAFA for help 87%, have experienced financial issues since leaving the armed forces. If implemented correctly, Strawmill Homes can work to meet the needs of the UK's veteran population.(89)

Summary - Employers providing housing for employees was commonplace in the past, becoming less so in recent decades. Police houses, farmhouses, mill-worker homes and military accommodation were abundant, with only military accommodation and a number of farmhouses remaining. Providing on-site MMSC housing for employees emulates these successfully implemented schemes from our recent history and creates significant benefits for both parties.

STRAWMILL HOMES - HOUSING DESIGN AND DEVELOPMENT

The University of Bath has untaken a significant amount of research into straw as a construction material, even going so far as to assist Bristol-based Modcell with their MMSC designs. The University of Sheffield have also been heavily involved in non-straw MMC designs. They have a large, well-equipped prototype and research facility called the Advanced Manufacturing Research Centre (AMRC), located on the outskirts of Sheffield.

The AMRC is within an hour's drive of Scunthorpe, Strawmill Homes' proposed factory location. The site is a designated site for putting academic ideas into practice as prototypes. As well as working with many high-precision manufacturers, such as Airbus, Boeing and Rolls-Royce, they also have experience of working with MMC housebuilders, such as Laing O'Rourke and Legal and General.(93) Given their location and extensive expertise, the University of Sheffield and their AMRC will be consulted to assist in designing a range of MMSC house types for Strawmill Homes.

Further collaboration between the AMRC and the University of Bath – who have established expertise in straw constriction – would also be advantageous.

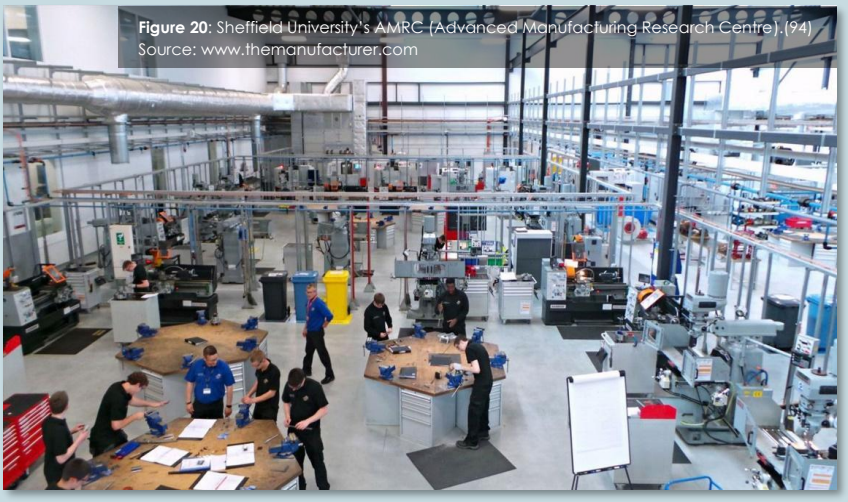


Figure 20: Sheffield University's AMRC (Advanced Manufacturing Research Centre).(94)
Source: www.themanufacturer.com

The design and planning stage would not be limited to home designs; the layout of the factory, the machinery used and how the build process can be made as safe and efficient as possible are other major considerations. Robots can already undertake construction tasks with greater precision, requiring fewer materials and less labour than traditional on-site building techniques. For example, Sheffield University's AMRC has developed a robotic arm which spray-paints the walls of homes. It consistently produces an even finish with minimal overlapping of paint, therefore reducing the volume of paint required. This innovation reduces both the build costs and the environmental impact of building new homes.

Strawmill Homes aims to design homes with efficient assembly in mind. Primarily, this means utilising standardised wall panels and standardised room pods. 'Pod' is a term used for preassembled rooms, such as kitchens and bathrooms, which are constructed in a factory and transported to construction sites whole. This is unlike traditional construction and some other forms of MMC, where kitchens and bathrooms are installed on-site.

Using standardised pods produced on a large scale reduces build costs and construction times, while improving build quality. For example, all house bathrooms, regardless of the size and layout of the rest of the property, could be one standard size with a toilet, a sink and a bath with a built-in shower. Likewise, all en-suite shower rooms could be one standard design.

Figure 21: MMC 'pod' being craned into position.(95)
Source: Liz Male

Pods will have identical layouts in each home although residents will, of course, have the autonomy to decorate and refurnish their homes once they move in, adding an element of individuality to each build. Utilising a high degree of standardisation also reduces construction delays and costs. For example, if one panel (wall) of a building is damaged, an identical wall piece can be inserted quickly and easily into its place.

Many housebuilders have large catalogues with dozens of standard house types which they build. A large list of standard house types leads to increased build costs and decreased build quality. Conversely, Strawmill Homes will have a concise, refined catalogue of homes. This was the approach taken by Britain in the inter-war and post-war years, and it successfully enabled to the nation to build a large quantity of homes, combatting the housing crisis of the time. These efforts focused on producing large quantities of similar three-bedroom, semi-detached homes, with limited design variations.

When standardising house components, such as wall panels and pods, a greater emphasis will be placed on varying street-scenes, to retain diversity on MMSC estates. Furthermore, house designs can be built in varying configurations. For example, the same house type can be built as a mid-terrace, end-terrace, semi-detached or detached house, with minimal design variation required. This enables a varied street scene while also enabling the efficient design principles proposed in this review.

An initial review and proposal for Strawmill Homes' house types has been undertaken below. These house types aim to provide sufficient variety to meet the majority of the public's needs, while also enabling a varied street-scene and maximising standardisation. The 12 prospective house types are outlined on the following page:

Table 5: A summary of a proposed house types for Strawmill Homes. This the minimum number of house types required to meet the needs of the public, while creating an attractive street-scene and maximising build standardisation.

Property Type	Bedrooms	Storeys	Integral garage	Main Configuration	Secondary Configuration	Notes
Flat	2	5	No	Flat	N/A	Standardised low-rise block of flats (maximum of five storeys in height). To include two types of two-bedroom flat: one with a dining kitchen, the other with a separate kitchen and dining room.
Flat	2	5	No	Flat	N/A	
Bungalow	2	1	No	Semi-detached	Detached, terraced	
House	2	2	No	Terraced	Semi-detached	
House	3	2	No	Semi-detached	Terraced, detached	In order to provide a varied street-scene, two house types of differing appearance are produced for what will be mainly three-bedroom semi-detached houses, given their prevalence. One will have two double bedrooms and a single, with the second having three double bedrooms.
House	3	2	No	Semi-detached	Terraced, detached	
House	3	2	No	Detached, semi-detached, terraced	N/A	Corner-turner house type, designed for internal corners of developments with the front and one side elevation being attractive from the roadside, avoiding large areas of walls without windows and other aesthetically detracting features. This is a common practice on new build developments. This house type should be a close adaptation of another house type to aid standardisation and efficiency.
House	3	2.5	No	Semi-detached	Terraced	Two full stories with the third built into the roof space with dormer windows
House	4	2	No	Detached	Semi-detached, terraced	Built with an integral garage.
House	4	2	No	Detached	Semi-detached, terraced	Design A.
House	4	2	No	Detached	Semi-detached, terraced	Design B.
House	5	2	No	Detached	N/A	

It is unusual for traditional housebuilders to construct bungalows, as they are not as profitable as houses with an equivalent footprint. Despite this, the UK has an urgent need of more bungalows to accommodate our growing elderly population. With a social ethos, it is right to build a number of bungalows on new build developments to create diverse communities and meet this national shortage. It is acknowledged that local authorities sometimes require a small number of bungalows to be built as a condition of planning approval, so this issue is already being addressed on a small-scale.

In keeping with contemporary architectural trends, it is appropriate to provide an aesthetic for MMSC housing which offers simplicity and is not overly ostentatious. A lime render will be applied to MMSC homes to enable them to 'breathe', so that moisture can move from the inside of homes to the exterior, preventing damp and mould. Strawmill Homes will create homes which are rendered, painted white and fitted with contemporary grey windows.

Figure 22: LILAC, a Modcell MMSC development, Leeds(96)
Source: LILAC (Low Impact Living Affordable Community)

The Modcell MMSC development shown in in Figure 22 has flat roofs which generally require more maintenance than pitched roofs, this is contrary to the aim of making low-cost homes. It is therefore more appropriate to build sloped roofs. Roofs can also be made in a modular fashion, with structurally insulated panels (SIPS). SIPS are factory-made roof sections which are craned into position once on-site, as shown in Figure 23.

Figure 23: A SIP being craned into position.(97)
Source: www.designfor-me.com

New homes should look attractive while achieving their design aim of providing environmentally-friendly, low-cost homes for people to live in. This aim should not be comprised by the implementation of overly-excessive architectural flare. Homes should be robust and fit for purpose as a priority. In meeting these aims, simplistic, contemporary homes can be created en-masse in a new architectural style that defines our generation and leaves a legacy for our descendants. Externally, homes

will look similar to the house shown below in Figure X; minimalistic and in keeping with current contemporary design.

Figure 24: Inspiration for exterior for Strawmill Homes, white rendered exterior, contemporary grey windows and doors and a minimalistic style. Note property in photograph is not MMSC however it's appearance could be replicated.
Source: www.thebestbuildteam.co.uk

Manufacturing 12 property types on a new development is not uncommon. Many large housebuilders often construct between 12 and 15 house types on developments of 100 or more homes. Despite Strawmill Homes having a catalogue of 12 house types, most developments, unless very large in size, will feature a small selection of these 12. This is in keeping with Strawmill Homes' aim to build a small number of well-designed house types on all of its sites, as well as providing variety in the sites by utilising different house types and changing their standing in relation to other properties. Further aesthetic appeal can be created by way of well-considered estate layouts. A strong emphasis on symmetry, greenery and public space design can create intrigue and character.

The aim of Strawmill Homes is to push housebuilders in a more environmentally-friendly and socially-beneficial direction, in a way which is aligned to national objectives. With this aim in mind, the design of Strawmill Homes' properties should consider the use of rainwater harvesting, PV panels and other such features as to incentivise established housebuilders, by way of competition, to invest in these innovations. With the aim of encouraging private-sector investment in MMSC, Strawmill Homes could also produce online training courses and other technical information to promote the dissemination of MMSC technology.

As in MMC, the customisation of interior elements, such as kitchen surfaces and flooring, will be available in MMSC. Customisable elements will however be kept at to a minimum, with only a relatively small number options available. This ensures that build costs can be driven down by way of large-scale orders.

New homes are typically sold 'off-plan', without purchasers viewing the property and often without viewing a show home of the same house type which they are purchasing. Show homes will be kept permanently at the Scunthorpe MMSC

factory site to disseminate information and showcase MMSC technology. These show homes can also be used for buyers to inspect the quality of homes.

It is recommended that interactive CGIs (computer-generated imagery) and virtual reality (VR) are utilised by Strawmill Homes. CGIs of house types can be viewed by customers to assist them in visualising their new home and the different customisation options available to them. This is a great benefit to customers as off-plan sales are made prior to the completion of construction works. This will aid the sale of homes and enable purchasers to choose their home customisation options remotely with interactive CGI or VR.

At present, many housebuilders are inefficient, using lengthy face-to-face meetings with customers to discuss customisation options. The technology already exists to circumvent this long-winded process, and given the small number of house types in Strawmill Homes' catalogue, it would be easy to implement. This approach will reduce costs and improve customer satisfaction given their greater degree of control.

In order to reduce ongoing energy and water use in homes, smart meters will be installed. These could link to mobile phone applications to help homeowners monitor their usage and expenditure. As Strawmill Homes will use a small number of house types, large quantities of energy data will be available so that home owners can compare how their energy use compares to others in the exact same home. Unlike other smart meters, occupiers of Strawmill Homes' properties could review their energy data via an app or website to see how their usages differ from the average resident in their individual house type. Research has shown that combining this data with visual representations (such as green smiley faces and red unhappy faces) can influence people to change their habits. Utilising modern technology in ways such as this will begin to amend occupiers habits, reducing water and energy consumption.

It is important that those occupying MMSC homes maintain them correctly. Occupiers may need to make habitual changes to achieve this, for example, by avoiding non-breathable paints when decorating. While new home purchasers will be made aware of important information by Strawmill Homes, subsequent occupiers may not be: this could result in defects caused by occupier error. A way of easily identifying MMSC properties and advising consecutive occupiers on maintenance must be devised.

MMSC developer Modcell fit a pane of glass into an internal wall, to showcase the straw behind it. As well as being an attractive and intriguing feature, this also serves as a means of advertising the property's construction method. Without a feature such as this, even professionals such as building surveyors, may misidentify MMSC construction. QR codes could also be located in an area of a home not likely to be painted over, linking occupiers to relevant home information when scanned. Information will also be made available via a Strawmill Homes app or website. Via the dissemination of information, surveyors, conveyancers and other professions involved in sales will become educating in MMSC, so they can make purchasers aware of any habitual changes they may have to make.

In recent years a concerted effort has been made to improve the insulation of UK homes. As outlined in Section 1 however, overheating is estimated to occur in 19% of bedrooms and 15% of living rooms(45), with this figure to rise as a result of climate change in the near future. Combined with an ageing population, making well-insulated homes which are not designed to cope with greater seasonal variation in a

era of climate change could increase NHS expenditure. In 2016, 400 heat-related deaths occurred in just one day.(98) Although this would be subject to further review, it would be logical to install heat pumps in MMSC homes which are capable of cooling as well as heating. This technology is utilised throughout much of the world, however, many air source heat pumps currently installed in the UK are only designed to provide heating and not cooling. The electricity utilised to power heat pumps could be offset by installing PV panels on properties. White external walls will also reflect heat and will reduce the risk of overheating.

ONGOING MAINTENANCE

It is common practice in the automotive industry for cars to be serviced annually. This is not the case for traditional homes, whereby issues are typically reported once owners have identified them. It is advised that while MMSC homes are in their infancy, regular inspections should take place, similarly to programmes of inspection and servicing undertaken in the automotive industry. This has several key benefits:

- Any issues which occur following construction can be rectified at an early stage, preventing defects from becoming exacerbated, costly and inconvenient to rectify.
- Professional home inspectors are more likely to identify issues when compared with homeowners, who typically have little to no knowledge of construction, particularly regarding MMSC.
- Issues with user-error can be rectified early. Home purchasers and occupiers should be adequately educated on maintaining MMSC homes prior to occupation though through human error or choice to ignore these instructions, damage can still be caused. It is important to rectify any human error as soon as possible to prevent significant damage from taking place. This is an area of high risk which could cause significant damage to the reputation of Strawmill Homes and MMSC. Regular home inspections can significantly mitigate this risk.
- Defects can be recorded by Strawmill Homes' approved home inspectors. Defects will be logged and categorised, and any trends will be addressed with maintenance, improvements to future designs and improved means of educating homeowners.

There are a number of options available for implementing home servicing plans for MMSC homes. Home service plans could be offered in a similar fashion to that of new car servicing, whereby servicing is discounted or free for the duration of the warranty period, with additional services offered for a fee once the warranty has expired. Log books with records of servicing can also be kept online and passed from one homeowner to the next. Alternatively, properties could be sold leasehold, with a home servicing cost included in a service charge to ensure the longevity of homes.

The cost of instructing a building surveyor is significant, and as such, residential property surveys are not undertaken regularly, tending to only take place when a property is sold. Strawmill Homes has a means of overcoming this barrier to regular home inspection. Home inspectors, specifically trained in MMSC construction, could survey entire MMSC developments in one sitting utilising standardised reports, specific to MMSC house types. There would also be no travel time between properties on an estate. These highly specialised surveyors, utilising efficient approaches will lower the cost of home inspections to an affordable level, making regular MMSC property surveys feasible.

Encouraging regular home inspections and maintenance would see a move away from the current reactive approach to home maintenance to one which is more proactive. This would mitigate the risk of significant defects, reduce home maintenance costs, reduce the likelihood of significant 'one-off' home maintenance expenses, increase the longevity of housing and improve the quality of life for occupants.

MORTGAGES

Mortgagees maintain their own policies regarding lending. For lesser known forms of construction, such as individual types of MMC including MMSC, lenders often refer to surveyors or make decisions based on the presence of a suitable new build warranty. Provided that they are well-designed and capable of obtaining a suitable new build warranty, MMSC homes should be suitable mortgage security for mainstream mortgage lenders.

Mortgage lenders are more likely to consider lending on MMSC homes if a large number are built, as this would increase the financial incentive for lenders to review and affirm lending.

In the unlikely scenario that mainstream lenders are not willing to lend on MMSC homes, then some government assistance will be required until a time when mortgage lenders have adequate confidence in MMSC. Confidence will grow once a sufficient number of defect-free MMSC homes have been built over what lenders deem to be a reasonable period of time. Building a large number of MMSC homes to serve as evidence of their durability, desirability and potential lending market is the most appropriate means of ensuring mainstream mortgagees provide financing for these homes. The show homes and employee's homes built at the MMSC factory site in Scunthorpe will serve as a first step to proving the high quality of Strawmill Homes' buildings.

If lenders are reluctant to offer mortgages on MMSC homes, the government has a number of ways of overcoming this issue, including:

- Offering a government-backed new-build guarantee on MMSC homes, therefore providing confidence to lenders.
- Offering government lending. The government could create a lender which offers mortgages on Strawmill Homes. Funds could also be raised for this government-backed lender via the sale of green bonds, reducing the need for public funding.
- Implementing legislation which dictates that lenders cannot refuse lending on properties built in MMSC/built by Strawmill Homes simply because of their construction method.

It is hoped that the aforementioned scenarios will not be required, as there is no reason why MMSC homes would not be deemed as suitable security for lenders. At present, MMSC homes have been financed by mortgage lenders, though given their small number, it is unclear how forthcoming all lenders will be in providing a suitable range of lending options for the public.

In order to provide further confidence to lenders, surveyors and other stakeholders, information will be distributed to these property professionals to enable them to understand MMSC construction. In doing so, this will remove barriers to lending and any scepticism. This could come in the form of concise, downloadable information packs, designed specially to educate professionals such as conveyancers and surveyors on MMSC. These professionals can then advise their lender clients more accurately.

SECTION SUMMARY

This section has outlined the optimum means of producing a large number of MMSC homes. Without government financial assistance, it is highly unlikely that MMSC homes will become the new norm for residential construction. Failing to capitalise on this method of building would be a missed opportunity for the nation, as it offers huge social, environmental and economic benefits. Unlike other publicly funded organisations, the concept organisation - Strawmill Homes - would be self-funding following initial government investment.

Scunthorpe, north Lincolnshire is proposed as the location for the first Strawmill Homes factory. Coincidentally, the town and surrounding commuter settlements have high unemployment with many residents possessing transferable skillsets well-suited to MMSC construction.

Besides initial funding, only minimal government assistance is required for the project's success. Despite this, the project would be more effective should the government consent to the recommendations in this review. These include Strawmill Homes' having special status to expedite planning applications and have pre-approved house type designs; these powers being subject to possible suspension in areas of special planning status sensitivity, such as national parks, conservation areas.

Although Strawmill Homes could receive government funding to purchase land on the open market in a way akin to that of traditional developers, it would be more effective to have further government support. This would involve building on land owned by Homes England. Homes England is obliged to act in the public interest, so the aspirations of both organisations would therefore be aligned. Furthermore, Strawmill Homes provides a great opportunity to build a large number of new council houses, taking the burden off local authorities.

The proposal to build MMSC homes for employees at Strawmill Homes' factory site has numerous social, environmental and financial benefits.

It is essential to build as few house types as possible in order to reduce build costs while maximising efficiency and build quality. Where possible, building elements should be standardised, so they can be easily used in various house types.

Once Strawmill Homes produces MMSC housing en-masse, it is anticipated that private sector investment will follow. Private sector companies following in the wake of the Strawmill Homes will benefit from reduced build costs brought about by: the availability of established supply chains, minimalised research and development costs and the increased availability of MMSC experienced professionals. Although Strawmill Homes has the potential to have significant, direct benefits, its main aim is to act as a catalyst for private-sector investment in MMSC. Realising this aim would see the current housing and environmental crises combatted at the earliest possible opportunity.

A number of government aims can be achieved if these proposals are implemented including the 'levelling up the economy', 'northern powerhouse' and 'building back greener' initiatives. The uptake of apprenticeships and T-Levels will also be realised. Furthermore, this proposal enables a range of objectives set out in the government's 25-year environmental plan,(99) while also simultaneously mitigating the housing crisis.

SECTION 4

REVIEW SUMMARY

SUMMARY OF REVIEW

The Key Issues of the housing crisis and the aspiration to emit net zero emissions by 2050 are of paramount importance and are highly time sensitive; it is crucial to solve both issues at the earliest opportunity. If traditional construction practises continue to dominate the UK housing market, neither objective will be achieved.

The solution is for the UK is to build a large proportion of new homes in factories in a fashion known as modern methods of construction (MMC). This approach will combat the housing crisis as homes can be built more quickly and with less labour. Uptake in MMC has been limited to date, with no significant uptake among existing large housebuilders. MMC homes are constructed using a variety of building materials. Many are not environmentally friendly, particularly those which use large quantities of concrete and steel. Other MMC facilities utilise materials which are in short supply, are expensive, or both; timber is a good example of this. The solution to both issues, with the best likelihood of success, is to build homes using straw, in an innovative fashion coined Modern Methods of Straw Construction (MMSC). Despite only having minimal use in the UK, MMSC is tried and tested and offers an ideal solution to the country's aforementioned crises.

MMSC homes are built in factories using agricultural straw. Straw walls provide excellent insulation and structural support. Timber-frames encapsulate the straw interiors, although far less timber is required than in traditional timber-framed properties. These homes can be built quickly, at a low cost and to a high standard. Crucially, this method of construction enables large volumes of CO_2 to be stored in the fabric of the property.

Each MMSC home removes CO_2 from the atmosphere as opposed to releasing it, unlike most traditional buildings. These homes are well-insulated and therefore have low running costs, reducing pressure on the national grid while making homes more affordable to run. As these homes are built of natural building materials, they have a limited long-term impact on the environment. Once MMSC homes have reached the end of their life, they can be dismantled and burned as biofuel for power generation; a stark contrast to most other homes which create a waste legacy once demolished.

The uptake of MMSC has been limited to date: partly due to a lack of awareness of this form of construction, and partly due to high build costs. As with anything mass-produced, large-scale production is required to reduce costs. Companies attempting to utilise this form of construction are too small and poorly funded to achieve this aim. Given the time sensitivity of the housing and environmental crises, it is proposed that a non-profit, government-funded organisation is created. The concept name for this organisation is 'Strawmill Homes'.

The organisation would create a large number of MMSC homes from a factory based in Scunthorpe. Although this organisation would have its own objectives and aims, its main function would be to serve as a catalyst to incentivise private-sector investment in MMSC, therefore alleviating the crises in a joined effort. Establishing this MMSC factory would lower MMSC entry costs, raise MMSC awareness, lead to the creation of established supply chains and result in a large talent pool of MMSC construction personnel. Over time, it is envisaged that MMSC would become the construction norm for the UK. Encouraging MMSC to become the prevalent method of construction in the UK is the closest the nation can come to a 'silver bullet' solution. The proposed solution should be supported wholeheartedly if the UK is to meet its environmental and housing aspirations.

SUMMARY OF PROPOSALS

- The UK government should fund a non-profit MMSC developer (referred to in this review by its concept name, Strawmill Homes).
- Strawmill Homes should locate its initial MMSC factory in Scunthorpe. This location is near to high straw yield areas, close to transport links, close to major ports for timber imports and will provide employment in nearby areas of high-unemployment.
- Strawmill Homes' aim is to 'de-risk' MMSC construction, raise awareness of MMSC, lower construction costs and establish supply chains, therefore incentivising private-sector investment.
- Strawmill Homes is to act similarly to that of a private-developer, though some of the profits are to be used to offset higher initial build costs; this would remain the case until production is optimised. Once achieved, profits can then be redirected into rapid organisational expansion.
- Strawmill Homes is to focus on building a large number of homes quickly. To achieve this, the organisation will utilise standardised building components, such as wall sections and pod rooms, where possible. A small number of house types are to be constructed on a large scale.
- Although government funding should be provided for Strawmill Homes to purchase land on the open market, the organisation should also be given first refusal to purchase land owned by Homes England and other public bodies, such as local councils. When acquiring land from councils, Strawmill Homes should be given special powers regarding the means of purchase. Options including payment in cash or by providing council houses to equivalent value of the land. The latter will reduce cashflow issues for Strawmill Homes, while providing local councils with much-needed social housing.
- In order to accelerate the construction of MMSC homes, Strawmill Homes should be given pre-approved planning status by the government for their house types. Strawmill Homes' house types should be designed within national planning guidelines and not require amending in different local authority areas. This avoids the need to redesign house types for every estate, which would increase costs and reduce build quality due to a lack of standardisation. Strawmill Homes' special status should be subject to repeal in areas of planning sensitivity, such as National Parks and conservation areas. Because Strawmill Homes aims to build a large number of homes quickly, this is of little consequence to the organisation.
- Strawmill Homes should have a significant degree of autonomy. This enables flexibility and the ability to rapidly make changes in a similar fashion to that of any private company.
- Strawmill Homes' MMSC factory should be located in Scunthorpe with the head office of the company located adjacent to, or adjoining the factory. MMSC properties should also be built for employees adjacent to the factory and head office buildings. This enables the enterprise's refined catalogue of house type to be trialled by live-in staff before they are occupied by the public. These trials will allow designers to iron out any flaws while avoiding public scrutiny, which could otherwise negatively impact the reputation of straw-bale construction.
- Increasing construction staff recruitment and retention rates is key to solving the housing crisis. A review of apprentice's minimum wages and the framework of grant funding payments to construction employers is required. All incentives should stimulate the uptake of apprenticeships and the high performance of apprentices.

Food, water and shelter are the cornerstones of our survival. The ongoing housing and environmental crises are therefore the two greatest issues facing human-kind. Combatting them using the means outlined in this review would be of significant benefit to the nation, and indeed the rest of the world. It is hoped that the successful implementation of MMSC will cause other nations will follow our lead, further mitigating carbon emissions and slowing - or even stopping - climate change.

This opportunity is too great to ignore. Failing to invest in MMSC now would be one of the largest missed opportunities of the 21st century, whereas embracing it will leave a legacy we can all be proud of.

ABBREVIATIONS, ACRONYMS AND DEFINITIONS

AMRC – Sheffield University's 'Advanced Manufacturing Research Centre' is proposed to be the location for further MMSC research and development. This facility is utilised for research and the creation of prototypes with existing MMC housebuilders employing the services of this centre.

Carbon Bank – The long term storage of carbon. This includes carbon stored in natural building materials such as timber and straw which is contained for the duration of a building's lifespan.

CITB - Construction Industry Training Board.

EPC – Energy Performance Certificate. Used to assess the energy efficiency of properties.

DEFRA – Department for Environment, Food and Rural Affairs

Farmer Review – 'The Farmer Review of the UK Construction Labour Model'. An influential review written by Mark Farmer and published in 2016. This review states that the UK's housing targets (building 300,000 new homes by the mid-2020's) cannot be reached if current practices of building predominately with 'traditional construction' are continued and that a significant increase in use of MMC is required to achieve national housing targets.

Front-loaded expenditure – Expenditure required at an early stage in a project, long before equivalent financial returns can be expected. A significant sum of front-loaded expenditure exposes an organisation to cashflow risks.

GDV - Gross development Value. The term used to describe the value of a development should it be completed with nil costs incurred. This is used in the process of valuing land.

GHG – Greenhouse gasses

GWP – Global warming potential. This is in reference to the potence of greenhouses gasses and their impact on global warming for their relative volume. The higher the global warming potential, the more harmful the gas.

House type – A term used by housebuilders to describe a house design. Large housebuilders typically build the same small number of house designs across the country. This reduces build costs and improves build quality. The lack of variety in housing is typically disguised by interspersing house types throughout a development.

Land Bank – Terminology used to describe land owned or controlled by an organisation. For example, well-established British housebuilders typically have large land banks at their disposal with teams tasked to actively acquire new land to enable a regular output of homes in line with organisation targets. Other organisations with large land banks include government organisations such as local councils and Homes England.

MMC – Modern methods of construction. Building a greater proportion of homes in a factory as opposed to on-site.

MMSC – Modern methods of straw construction. Terminology utilised in this review to describe MMC homes whereby a large volume of agricultural straw is also used in construction.

MMSC Straw Bales – A term used in this report to describe straw bales which have been designed and produced specifically for use in straw construction. This would involve bales being produced by baling machines designed for this purpose.

Off-cut – Waste pieces of construction materials which are cut from larger ones and which are subsequently too small to be usable.

Off-plan – Houses being viewed using plans and drawings and not in person. Commonly used in reference to houses being 'sold off-plan' (i.e. without purchasers viewing the property). This is typical for new build properties where a sale is agreed prior to construction being completed.

On-site – Referring to work undertaken on a building site, at the location where the completed homes will remain permanently. For example, traditionally-built homes require the majority of construction to take place on-site. MMC in contrast, involves a greater proportion of the construction process to be completed in a factory (off-site) with building components be transported to, and assembled on-site.

Off-site – At a location other than where the completed building is to be sited permanently, such as in a MMC factory.

PV panel – Photovoltaic panels. Utilised to capture solar energy which can be converted into electricity.

RICS – The Royal Institute of Chartered Surveyors

SIP / SIPs – Structural insulated panel(s). A term used for panels (a section of wall or roof) which is already insulated and transported to site for assembly.

Strawmill Homes – The concept name for a government-funded, non-profit housebuilder designed to build a large number of low-cost MMSC homes. Strawmill Homes is envisaged to act as a catalyst, incentivising private sector investment in MMSC homes.

Street-scene – The aesthetics of housing collectively on a new build development.

Substructure – The section of the building which is constructed below ground level (i.e. foundations etc.).

Superstructure – The part of the building which is constructed above ground.

TMC – Traditional methods of construction. On-site construction which utilises bricks and concrete blocks.

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