Evaluation of Environmental Pollution of Housing Industry and Introduction of Modern Methods of Construction

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Abstract: Using data compiled from Powell's and Rosa's research on the CO2 emissions generated by houses at different stages of their lives, the paper examines and analyses the UK's externalities generated by residential properties and their environmental impacts. The paper also estimates that a single house's scale of ecological externalities is equivalent to 270 tonnes of carbon emissions. In the second half of the research, the paper focuses on the MMC construction system, which Innerspace Ltd initially introduced. On average, MMC homes reduce CO2 and annual Kw usage by c60% below current building regulations. By analysing company financial data and market status, research concludes that the sustainability of the MMC system and its accessibility for providing a more environmentally friendly and cost-effective in the UK.

Keywords: Residential Externalities, Environmental Impact, Global Sustainability, Housing Construction.

1. Introduction

1.1 Background

The construction industry plays a vital role in meeting different human needs, including housing, schools, and transport infrastructure. This paper adopted some papers to evaluate the effect of the Housing Industry [1-3]. At the same time, as the self-interested nature of humans, producers and households ignore the negative impact brought on the societies. Research shows that building sector expense of intensive use of natural resources and high degrees of energy consumption, in the UK, over 84% (200 million) tonnes of minerals are extracted, and 28% of carbon emissions are contributed by the sector annually [4]. It significantly worsens the overwhelming global warming issue. It is believed that a new construction system needs to be implemented to meet net harmful carbon emissions and minimise the irreversible consequences. With the high precision machinery production, the introduction of MMC provides a cheaper and greener way of housing buildings. At the same time, less time consuming and minimum labour requirements, MMC also reduced the problem of unaffordable housing.

1.2 Related research

The study on environmental impacts of the UK residential sector by Rosa [2] points out that the "construction industry contributes significantly to different environmental impacts including global warming and natural resource depletion", "(more) sustainable home design, including a more energy-efficient house, envelops "could help to deliver a more sustainable housing stock in the UK". Esteban [5] suggests that "housing externalities are large", and it closely affects the welfare of nearby neighbourhoods and local societies. Several historically published research addresses the environmental impact and negative externalities of residential sectors. Those reports cover a wide range from economic impact to moral hazards. Since there is a limited research time, there are two main reports used to establish the fundamental philosophy of this paper.

The research [2] concludes that the "use stage contributing most to all the impacts due to the energy consumption" (Figs. 1-3), illustrate the GWP for detached, semi-detached and terraced house over the lifetime of 50 years (Fig.4). Research also specified the energy usage of different construction material for a semi-detached home (Fig. 5, Table 1) [1].

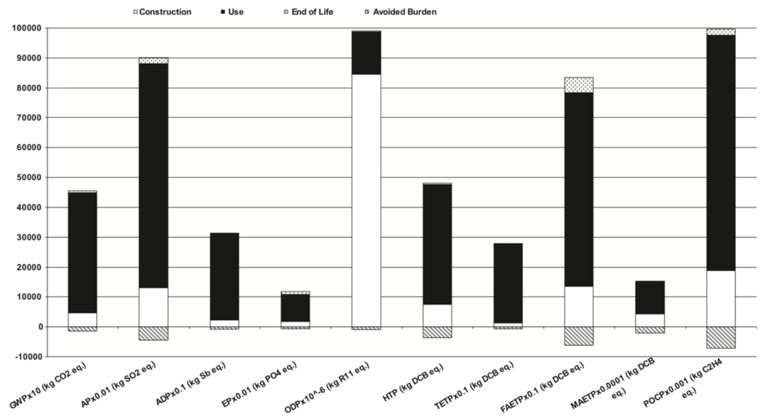

Figure 1. Life cycle impacts of the detached house over the lifetime of 50 years showing the contribution of the life cycle stages.

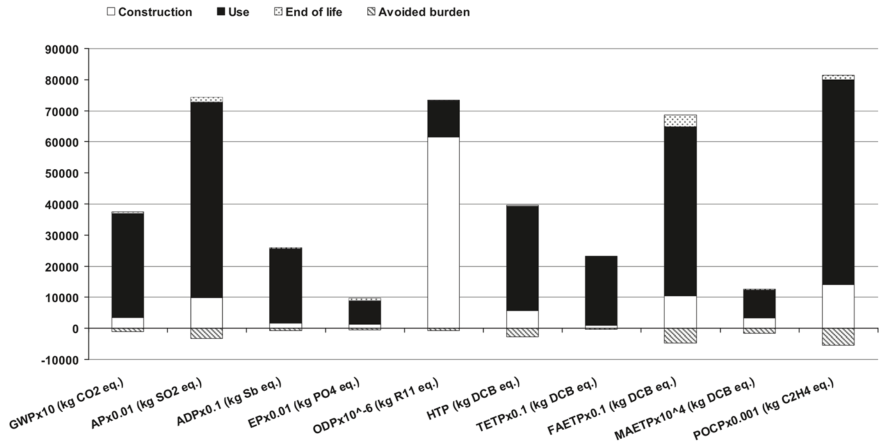

Figure 2. Life cycle impacts of the semi-detached house over the lifetime of 50 years showing the contribution of the life cycle stages.

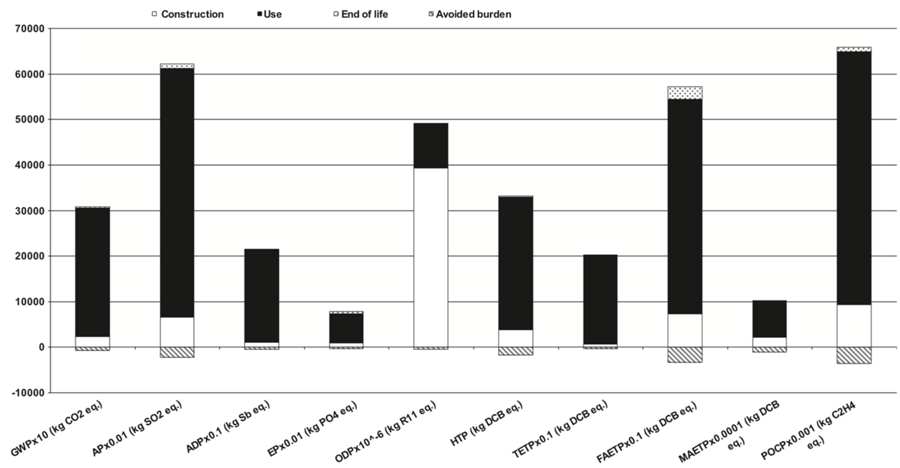

Figure 3. Life cycle impacts of the terraced house over the lifetime of 50 years showing the contribution of the life cycle stages

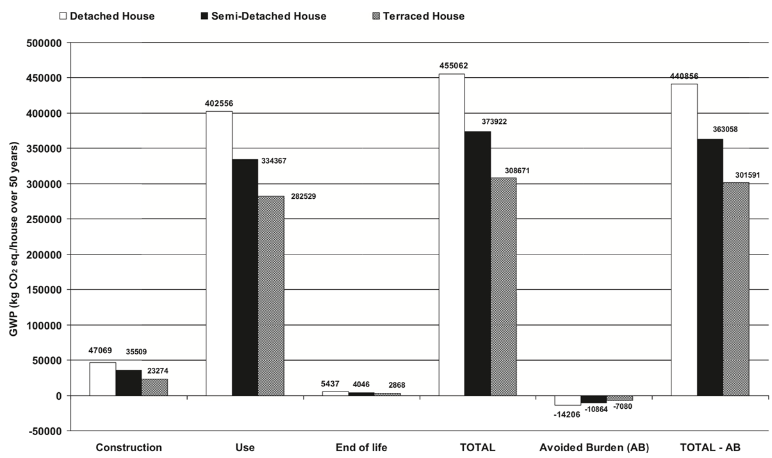

Figure 4. GWP for the detached, semi-detached and terraced house over the lifetime of 50 years, showing the contribution of the life cycle stages.

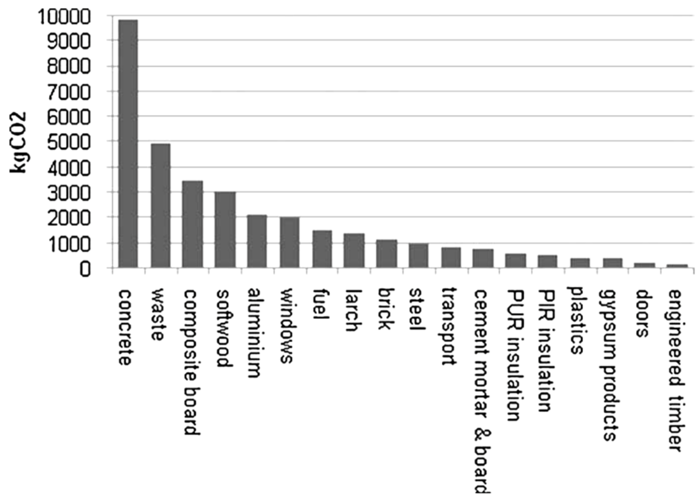

Figure 5. Summarised inventory results showing embodied carbon in construction, inclusive of offsite frame manufacture

Table 1. Energy consumption and carbon dioxide emissions by different category

Category	Material	Quantity (kg)	Emissions ($kgCO_2$)	Primary energy (MJ)
Metals	Aluminium	260	2140	40,260
	Steel	251	956	10,722
Minerals	Brick	2264	1175	18,510
	Cement (mortar/board)	2023	798	12,997
	Concrete	56,651	9863	72,142
	Gypsum plaster product	1349	413	7207
Openings	Windows	1277	1996	40,584
	Doors	142	246	4624
Plastics	HD polyethylene	56	90	4330
	LDPE	29	72	2558
	Polyisocyanate insulation	187	561	13,477
	Polythene	146	285	13,152
	PUR insulation	195	585	14,058
Timber	Composite board products	4330	3462	64,116
	Larch	1315	1421	15,090
	Engineered timber	222	152	2811
	Softwood	6792	3056	50,262
Fuel	Mains gas (kWh)	1107	226	4128
	UK Grid electricity (kWh)	11,106	948	12,462
	Diesel (1)	2070	363	5328
Waste		5350	4934	96,728
Transport	Factory gate to site	9372 tkm	883	13,131
Total:			34,625	518,677

1.3 Objective

This study uses carbon dioxide emissions and carbon prices to quantify the environmental impacts and negative externalities generated by housing. It then briefly introduces the new construction method (MMC), compares it with traditional building systems, presents the advantages and disadvantages of the MMC system and assesses the market accessibility. After that, the paper concludes with some potential issues that occur in the modern construction sector and some possible solutions. Finally, the paper also points out some of the limitations of the formulae.

2. Data and Methodology

2.1 Universe

The study area encompasses the environmental costs generated by a three-bedroom, semi-detached house with a total footprint area of 45 m2 and a total internal volume of 220.5 m3 in 50 year lifetime [6]. Focusing on environmental impacts includes the energy usage in production, use stage, deconstruction, and the energy usage in households' daily operations.

2.2 Data Sources & Research Base & Frame Work

This paper is based on Powell's [1] "An embodied carbon and energy analysis of modern construction methods in housing: A case study using a lifecycle assessment framework." Powell established the lifecycle process flow chart framework of housing energy usage in different stages in the research. The paper provides the environmental impact of using different metals, materials, and fuels during housing construction. "Environmental impacts of the UK residential sector: Life cycle assessment of houses", Rosa specified that during 50 years of a housing lifetime, 90% of CO2 was generated from usage, 9% from construction, and 1% from deconstruction [2]. Moreover, the estimation of environmental impacts is based on the LCA study that follows the ISO 14040/44 methodology [7].

The data in this paper are generated using a technique known as Life Cycle Assessment (LCA). ISE 14040/44 LCA is a method that compiles and evaluates a product system's inputs, output, and potential environmental impacts throughout its life cycle [8]. It considers all the impacts associated with the production and use of housing, from the first environmental impact to the last.

In Monahan and Powell's paper [1,2], they argued that there are three main stages in a housing lifetime (Fig.6). Including production, use stage and end of life (deconstruction). 2.3 Pollution in three stages.

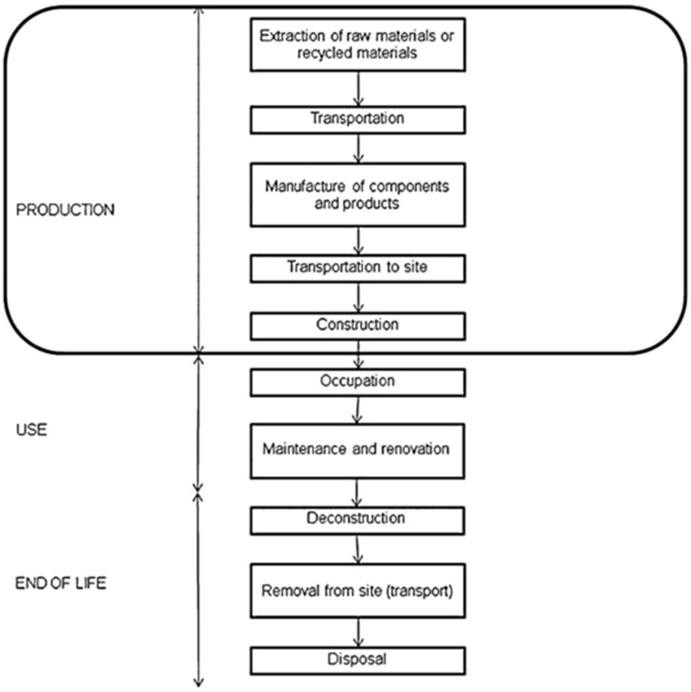

Figure 6. A simplified lifecycle process flow chart showing production boundary for a semi-detached residential house

Including production, use stage and end of life (deconstruction).

2.3 Pollution in three stages

$$\sum E_c = x_m + x_t + x_p + x_{ts} + x_c + x_w \quad (1)$$

$\sum E_c$ refers to the total carbon emission during the construction stage (Table 1). Where x_m represents the carbon emissions during the process of extraction of raw materials and recycling materials such as minerals and timber. The x_t shows the emission from transportation, and x_{ts} specify the emission from transportation on the site. The term x_p illustrates the energy use throughout manufacture of components and products. Lastly, x_c outline the energy consumed during the housing construction.

$$\sum E_u = [x_g + x_e] * \quad (2)$$

$\sum E_u$ represents the total carbon emission during the use stage (Table 2).

Table 2. Individual energy consumption summary by 50 years

	Daily uses in kWh	Annual usage in kWh	Equivalent usage in GJ	Carbon emissions kge	Individual consumption in 50 years (t)
Gas	8	2,922	10.52	902	45.1
Electricity	33	12,053	43.39	3,724	186.2
Total					231.3

$x_g + x_e$represents to main energy consumption by each individual in the UK (gas and electricity). N is a constant showing the average number of people per household in the United Kingdom. In this research paper, the value of N is taken as 2.36, which is the median households size between 2000 and 2022 [9].

$$\sum E_d = x_t + x_{lf} + x_{br} \quad (3)$$

The total carbon emission of deconstruction $\sum E_d$ shows different energy use from deconstruction. Which include the energy consumption of x_t direct deconstruction, x_{lf} land fill costs, and x_{br} waste incineration plants costs.

2.4 Total environmental costs

$$\sum E_t = \sum E_c + \sum E_u + \sum E_d \tag{4}$$

Total pollution generated $\sum E_t$ are measured by the direct carbon dioxide emissions plus indirect emission, the carbon emission in order to produce equivalent amount energy. $\sum E_c$, $\sum E_u$ and $\sum E_d$ represents total carbon emission during the construction stage, use stage and deconstruction stage respectively (Table 3).

Table 3. Monetary value of carbon emission

	Construction	Use	Deconstruction	Total
Carbon emission/tonne	34.6	231.3	4	270
Monetary cost				£4,900

$$\sum V_c = \sum E_T \times P_c(p_a, p_h, p_d, p_a) \tag{5}$$

$\sum V_c$ is the monetary value of carbon emission. It is argued that evaluating the monetary impact of carbon emission such as rise in sea level or increasing health risk contains too many uncertainties and variables. A better calculation can be used is carbon price. P_c is the value of carbon price, taking the value of 2021 carbon price, £18.08 per tonne of carbon dioxide-equivalent (t CO_2e) [10].

3.Results

3.1 Free market failure: negative production externalities

This paper argues that left in the free market, the output level for housing function at marginal private cost (MPC) equals marginal social benefit (MSB). The marginal private benefit is more significant than the marginal social benefit. Homebuyers and the building industry only consider their personal benefits. In other words, households only consider the housing price or mortgage repayments; firms only consider the cost of construction. Nevertheless, the optimal level of consumption and production of housing for the society operates at marginal social cost (MPC) equals marginal (MSB). At this level of consumption, the negative impact of pollution and other external costs is considered. The economy maximises the total welfare.

In an economical, efficient housing market, there would be no externalities. Nevertheless, as the market fails to operate at the optimum social level of production, the market tends to misallocate resources. In the environmental view, left in the free market, the housing would be overproduced and underpricing. Climate change and greenhouse gas emissions are frequently associated with negative externalities. Research from the Manual Loa observatory in Hawaii argued that between February and March 2021, the CO_2 concentration in the atmosphere exceeds 417 parts per million (ppm), 63% more concentrated than in the 1750s [11]. The construction and occupation of the building contribute almost a quarter of total global CO_2 emissions. More than 5% of global CO_2 emissions are attributed to the manufacture of cement, which is an essential material in the construction process.

3.2 Carbon emission

According to Monahan and Powell's s research [1,2]. The total energy consumed by a semi-detached residential housing construction is 519GJ, which requires emitting 34.6 tonnes of CO_2 to produce the equivalent energy. Table 2 shows detailed energy consumption by housing construction. Results show that 82% of total carbon emission was attributed to materials incorporated in the building, of which concrete emits 9.9 tonnes of CO_2.

The Office of Gas and Electricity Markets (Ofgem) regulates the monopoly companies which run the gas and electricity networks (GOV.UK, Ofgem) [12]. According to Ofgem, the daily consumption of electricity and gas are 8kWh and 33kWh, respectively. Using the CO_2 emission factor of

0.309khe/kWh (BEIS 2018) [13], the amount of energy usage in 50 years is equivalent to 230 tonnes of carbon emission. Rosa noted that at the end of housing's useful life, each house generates 4 t CO_2. The main burden comes from demolition activities and landfilling of deconstruction waste. As a result, one individual house emits 270 tonnes of CO_2. Using the data from the 2021 carbon price, the monetary cost of housing usage is equivalent to £4,900 in 50 years of lifetime [10].

3.3 Government intervention: Carbon tax and pollution permit

Since May of 2021, the UK has introduced its own ETS, which applies to energy-intensive industries such as aviation and power generation. The scheme aimed to help the UK meet its goal of becoming a zero-carbon emitter by 2050 [14]. Carbon tax increases the cost of production in the construction industry. It would add directly to firms' variable costs, increasing marginal and average costs. With the constant average and marginal revenue, an increase in costs would lead to a fall in industry profit. However, the carbon tax might also be a strong incentive for businesses to invest in R&D and accelerate forward innovation in green technology and construction methods. In the long run, achieving the reduction of carbon dioxide emissions. Besides, the idea of "making the polluter pay" helps the UK economy internalise the negative externalities produced by the housing industry. Under the carbon tax, the consumers are likely to fave a higher energy price; this rationalised carbon consumption and encourages households to spend on home insulations or fuel-efficient vehicles.

However, the carbon tax introduces inequalities. It risks having a regressive effect on poorer households. Low-income families spend a higher percentage of their income on energy usage. An increase in energy cost largely reduces low-income households' disposable incomes. Consequently, they suffer from a fall in living standards.

Additionally, the carbon tax would result in the domestic housing market being less competitive. Meaning the UK might face a reduction in foreign investment and housing supply. Plus, the introduction of the carbon tax would create cost-push inflation. Carbon taxation pushes the production cost of housing construction and other carbon-related industries, which drives up the average price in the UK economy.

Another scheme first introduced in January 2021 by EU ETS is the Emissions Trading Scheme (UK ETS) [15]. The government tries to control the carbon emission level and achieve the socially optimum level of carbon emissions by putting a cap on it. The UK government set out 80 million carbon emission allowances across different industries in 2022. Under UK ETS, firms may trade their permit with other firms. If the firm invented a low polluting construction method or material, the firm could sell the exceeded permit, in fact even making revenue from selling the permit. Like the carbon tax, ETS also inventive firms to lower their emissions. However, it is argued that reducing carbon emissions by setting carbon taxes and ETS is no longer the goal for the global environment. Achieving negative carbon emissions is the only way to minimise irreversible environmental costs.

3. Case study: Innerspace home group Ltd

3.1 Introduction

To reverse the impact of global warming, the global economy needs to achieve net negative pollution. Environmental problems must be tackled from a fundamental level perspective. Modern Methods of Construction (MMC) were introduced by Innerspace homes group Ltd [3]. MMC is a modular system of house construction where most building parts are pre-manufactured off-site. Factory processes and programs are highly controlled. Compared to the traditional construction method, MMC requires less labour capacity and is less time consuming — highly industrialised production allows uninterrupted housing production.

Moreover, a controlled indoor environment ensures repeatable quality and reduces unpredictable weather impacts. At the same time, minimise environmental impact during the construction process. This means under MMC, the cost of construction is hugely reduced. Lower housing price allows the firm to become more competitive and ensures the approach is more acceptable to the market.

Innerspace™ believes environmental and social factors are moving to centre stage, and astute principles and investors recognise that competitive and financial success is inextricably linked to more impact-driven business models.

The Sustainable Development Goals (SDGs) were adopted globally as a universal call to action to end poverty, protect the planet and ensure people enjoy peace and prosperity by 2030. SDGs introduced 17 goals, including climate action (NO.13) and affordable and clean energy (NO.7). Innerspace homegroup Ltd has committed, aimming to SDGs and focusing on improvement on citizens' good health and wellbeing (NO.3); sustainable cities and communities (NO.11); life on land (NO.15) and four other objectives, including climate action and affordable and clean energy [3,16].

With the precision factory built with designed-in green tech such as Air Source Heat Pumps and PV to capture solar gain, Innerspace homes reduce CO_2 and annual Kw usage by c60% below current building regulations – helping bring significant reductions in both fuel bills and carbon footprint on our planet. The planning permission will also seek to provide over 50% of the homes under a Discounted Market Sale (DMS) model - offering a range of 2-4-bedroom homes for sale to eligible purchasers at a discount of between 20-40% below full market value [3]. These homes then stay permanently affordable at their respective discounts, ensuring first-time buyers and middle-income earners are always able to get on the property ladder.

Moreover, the impact of Innerspace's MMC system has other positive spillover effects. It is argued that the introduction of advanced technology drives other businesses to use better methods. The company addresses social and environmental issues at scale, at the same time encourage other firms to use greener technology [3].

3.2 Statistical evidence

Innerspace spent three years on R&D, setting up the framework, including insurances, warranties and a secured pipeline. From the fourth year, the company raised 3 £2m in their first-round investment, producing 54 houses. In the years that followed, Innerspace maintained a steady production growth, an additional 100 houses per year. Five years after R&D, the company achieved a GVD of £130m, with a 6x exit multiple of £185m. This means the methods have become more socially accepted (Table 4).

Table 4. Innerspace home group Ltd factory setup

	Year 1	Year 2	Year 3	Year 4	Year 5
Cost of materials (£psm)	/	/	950	925	900
Expenses minus materials (£psm)	/	/	250	225	225
Total			1,200	1,150	1,125
Houses produced	54	150	250	350	450
Number of modules	162	450	750	1,050	1,350
Average per house sale (£psm)	0	0	1,200	1,150	1,125
Gross Revenue (million £)			30.6	41.06	51.64

Innerspace home minimises the negative externalities, and research shows that 67% of carbon footprints are reduced under the MMC system. The MMC factory was established in the third year after the company started selling housing. Construction material costs have shown a steady decline, which indicates that more carbon-free materials are used during the construction process. Besides, the company’s gross revenue reflects a positive growing trend, demonstrating the MMC system's feasibility and market competitiveness.

4. Conclusion

4.1 Review

Overall, the fact that left in the free market, where there is no government intervention, leads the residential housing market tends to be underpriced. Consequently, this creates a noticeable scale of negative externalities in the residential market. With the self-interested nature of humans, the negative impact on the global environment is ignored. The housing market donates a third of carbon emissions in the UK. Under the calculation, the paper concludes that 231.3 tonnes of carbon were emitted during the use stage, followed by 34.6 and 4 tonnes of emissions in the construction and deconstructions process, respectively. In total, every residential house generates 270 tonnes of CO_2 emitted, an equivalent of £4,900. To offset the issue of negative externalities, government intervention is essential. However, with the potential drawbacks of carbon taxes and pollution permits, the study shows that another construction system needs to be introduced to the market.

Innerspace Ltd introduced Modern Methods of Construction, which vastly reduced the environmental impact on the housing construction process. With more controllable and low marginal cost production, MMC houses offer a range of 2-4-bedroom homes for sale to eligible purchasers at a discount of between 20-40% below total market value. This means as well as increasing the sustainability of the housing construction sector. It also promotes the development of affordable houses.

4.2 Limitations and future research

The paper-based on LCA measurement. The "holistic" nature of the scheme means the analysation of the housing lifecycle can only be achieved at the expense of simplifying other aspects [7,8]. Besides, the LCA scheme focuses on a steady-state rather than a dynamic approach. It simplified the environmental impact model using a linear model. In the later research, I will develop a more complex model that could include the geometrical difference between the different regions and reflect on the fact that different housing types have different carbon emissions.

Moreover, the models only focus on the potential environmental impacts and exclude the impact of the housing market's economic, social, and stock value. Considering the practical use of the model, more economic factors need to be included in further research. Finally, it is argued that government should incentivise the development of a greener construction system; further research would focus on how the government should implement policies and better guide households to reduce the consumption of daily use of energy.

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