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Prefabricated Engineered Timber Schools in the United Kingdom: Challenges and Opportunities

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Abstract: Due to changing demographics, the UK faces a significant shortage of school places. The UK government aims to build large numbers of new schools to meet this demand. However, legally binding carbon emissions mitigation commitments might limit the ability of the government to adequately meet this demand on-time, on-budget, and within sustainability targets. This paper assesses the opportunity for prefabricated engineered timber construction methods to help meet the demand for new primary and secondary school buildings in the UK within these constraints. Building on a study of past government-led school building programmes and the state-of-the-art developments in engineered timber construction, this paper outlines the benefits that an engineered timber school building programme could have on a sustainability and procurement level. A strategy is then proposed for the wider adoption of engineered timber for the construction of school buildings in the UK, including detailed guidelines for designers and policymakers. The study concludes with recommendations for the adaptation of this strategy in different countries, depending on context-specific requirements, therefore promoting a generalised adoption of sustainable and efficient construction processes.

Keywords: engineered timber; sustainability; prefabrication; school buildings; modern methods of construction; fabrication; carbon

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1. Introduction

1.1. Challenges to School Provision in the UK

By 2024, the UK is anticipated to face a shortage of approximately 120,000 secondary school places. In 2016, the UK government committed to the delivery of 600,000 new school places by 2021 to address the rising number of pupils in the UK school system [1]. This includes a target of the construction of 500 new free schools, in addition to the refurbishment of a further 500 schools, as part of a £23 billion investment.

The construction and operation of buildings are responsible for approximately 40% of the UK's annual carbon footprint [2]. Without dramatic change, the construction of large numbers of new school buildings in the UK will therefore result in significant greenhouse gas emissions and other environmental life-cycle impacts. The UK government has put in place a legal commitment, through the Climate Change Act of 2008, to achieve net-zero greenhouse gas emissions by 2050 [3]. Beyond the commitments for sustainability, the UK government aspires to achieve a broader transformation and digitisation of the construction industry. More precisely, the UK Government's Construction 2025 strategy targets a 50% reduction of emissions, a 33% reduction in costs, and a 50% improvement in the speed of new construction. The strategy also targets a 50% reduction in the UK's total trade gap of construction materials and products by the year 2025 [4]. Building the necessary new schools required to meet projected demand could pose significant challenges to meeting these goals and the UK's legal obligations for greenhouse gas emission reductions.

1.2. Prefabricated Construction

The term "prefabricated construction", as opposed to "site-built " construction, refers to a construction process where large portions of a building are manufactured off-site in a factory environment and are later transported to site for assembly. It can be classified into different categories, depending on the extent of building product completion in the factory environment, including panelised, sub-assemblies, hybrid or volumetric systems [5,6]. Prefabricated construction has been shown to result in faster project delivery, reduced cost, higher quality assurance, reduced exposure of building materials to adverse weather conditions, reduced waste and improved worker safety and comfort [5,7–12]. Crucially, compared to site-built methods, prefabricated construction requires fewer workers and provides healthier, safer, and more regionally distributed construction jobs [8,13]. These benefits are further enhanced when off-site construction is applied at scale, where the opportunity for design standardisation increases. This is particularly relevant in government-led programs, where the volume of demand is high [5,14]. Prefabrication has been used successfully for the construction of schools and other public infrastructure in a number of countries worldwide, and has been shown to result in a faster and more cost-effective construction of such building types [7,15]. Early stage design decisions can substantially improve the total embodied carbon linked to prefabricated construction and should therefore form part of a holistic design approach, in order to exacerbate the benefits from it [16].

1.3. Engineered Timber

Timber has been used by humans as a construction material in forested regions worldwide since at least as early as the Neolithic [17]. In the 20th century, however, the widespread adoption of reinforced concrete and steel in construction resulted in these materials largely replacing timber in applications outside of some low-rise building types.

In recent decades, the development of novel "engineered timber" structural materials (Figure 1), in particular products which involve the lamination of solid boards of timber into large beam or panel components ("glue-laminated" timber and "cross-laminated" timber (CLT), respectively), have enabled the use of timber for a wider array of larger scale structures. Compared with "stick-frame" construction, which consists of individual sawn boards of timber fastened together into wall, floor and roof assemblies using screws or nails, glue-laminated timber and CLT combine boards into large, continuous elements which have higher design strengths and improved dimensional stability. Their production within a factory environment ensures high product quality and consistency [18]. In addition to their efficient construction and assembly process, engineered timber has great thermal insulation properties, substantially reducing the energy requirements during the building operation process [18]. Moreover, when used as part of a structure which has been designed with an effective fire safety strategy, such laminated timber elements can provide the same level of fire safety as that afforded by conventional steel and reinforced concrete construction. More precisely, the ignition of engineered timber elements is always followed by charring that provides not only an extensive period of auto extinction, but can also lead to the subsequent auto-extinction of the fire [19–25]. Overall, these novel engineered timber construction materials have been associated with a significant resurgence in the use of timber in structural applications globally in recent decades, and are the focus of this paper.

Prefabrication and off-site manufacturing are embedded in the production process of engineered timber structures. The production of engineered timber products includes a series of different steps, as shown in Figure 1 [18]. In construction where CLT and other engineered timber elements form the primary structure of a building, engineered timber elements are produced in a manufacturing facility and are then further processed using CAD/CAM software and digital fabrication equipment to accommodate connections and interfaces with other timber structural elements. These are then assembled on-site to form the primary structure. Their production in fabrication facilities ensures consistent properties in every production cycle and millimetre-level tolerances, substantially reducing the errors and risks associated with the construction process [9].

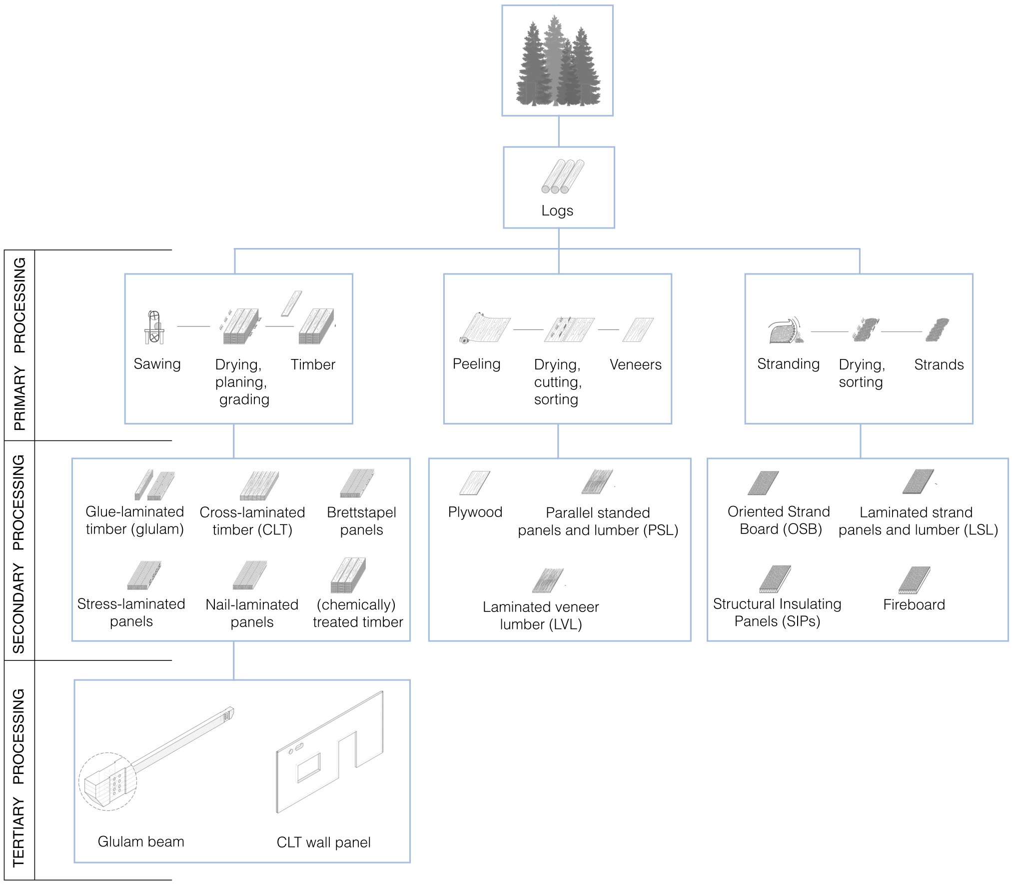

Figure 1. Timber manufacturing process (adapted from [18]).

This paper explores the potential for the use of engineered timber as a construction material for the delivery of government-procured prefabricated school buildings in the UK. An investigation of precedent school programmes is initially carried out and the challenges and opportunities of adopting this approach in the UK are identified. Focus is then placed on outlining the strategies and policies that are needed to facilitate the application of engineered timber in school buildings and the environmental, social and commercial benefits that this could bring.

2. Precedent School Programmes

2.1. Government-Led School Programmes in the UK

A large number of government-led school programmes have been carried out since the mid of the 20th century in the UK and internationally, as demonstrated in Table 1. In response to the urgent need for construction post World War II, in 1957, the Consortium of Local Authorities Special Programme (CLASP) was formed to produce prefabricated schools in the UK. Led by architects across two counties, the system used prefabricated light gauge steel frames and produced up to four-storey structures economically. The exterior of these structures could be clad with a multitude of panels to suit a variety of desired aesthetic characteristics. CLASP's modularity allowed for the adaptation of its configuration, generating diverse building layouts. CLASP's success stemmed largely from efficiency in the procurement chain—the system relied heavily on mass-production of primary structural elements and complementary envelope systems. Although originally intended for schools, the system was eventually also used for offices and housing. British Rail (Southern Region) also applied the principles of the CLASP system to construct its service buildings, thus spurring a wider range of applications than originally planned [26].

Over 1200 buildings with an average expected life of 60 years were constructed across the UK using the CLASP system. With its attributes of flexibility and speed of building, the CLASP programme matured into SCOLA (Second Consortium of Local Authorities) and MACE (Metropolitan Architectural Consortium of Education), extending to other parts of the country [27,28]. CLASP and subsequent prefabricated school building programmes in the UK demonstrated the potential for economical and rapid construction of school buildings using a modular, prefabricated approach. CLASP also demonstrated the benefits of cooperative pooling of resources by local authorities in the development of efficient supply chains for school construction. However, the perceived aesthetic shortcomings of these structures and their inclusion of asbestos-containing materials later shown to be hazardous to health led to these programmes ultimately falling out of favour in the late 1970s.

Following CLASP, SCOLA and MACE, the Building Schools for the Future (BSF) programme (2003–2010) emphasised a more context-specific and participatory approach to school design [29]. The scheme allowed school leaders, staff, and pupils to voice their needs and guide design professionals to develop tailored solutions while local authorities oversaw the process. Up to 70 schools participated in the programme. However, cost and time overruns, and the perception of the programme being overly bureaucratic, ultimately led to BSF being replaced with the Priority Schools Building Programme (PSBP). PSBP (2011–2015), and the subsequent PSBP 2 programme (2015–2021) aimed at establishing a more efficient design and construction workflow for schools provision but placed no particular emphasis on prefabrication [30].

In addition to ensuring a standardised and prefabricated construction, the Department for Education has taken further initiatives to ensure that the construction of new school buildings is aligned with the government's commitment to achieve net-zero greenhouse gas emissions. More precisely, GenZero is a £4m project between the Department for Education, Innovate UK, the Construction Innovation Hub (CIH) and the Active BUilding Centre (ABC). The goal is to transform the school design and procurement process using Modern Methods of Construction (MMC) to meet zero carbon emissions. The project is material agnostic and will deliver 200 new schools each year, placing the focus on manufacturability and whole life assessment.

Table 1. Precedent School Programmes.

School Programme	Date	Country	Funding		Prefabricated Construction	Construction Material		
			Public	Private		Steel	Timber	Agnostic
LTC	1954–1977	Australia	•		•		•	
CLASP	1957–late 70s	UK	•		•	•		
SCOLA	1961–1990	UK	•		•	•		
MACE	1966–1977	UK	•		•	•		
Gen7	1983–present	USA		•	•			•
BSF	2003–2010	UK	•					•
PSBP	2011–2015	UK	•					•
PSBP2	2015–2021	UK	•					•
PMSBP	2018–present	Australia	•		•			•
GenZero	2020–present	UK	•		•			•
StoraEnso	2020–present	Finland		•	•		•	

International School Programmes

At an international level, a series of public school programmes have been developed that have placed their focus on prefabrication and modular construction. In the late 1950s, Australia launched the Light Timber Construction (LTC) program to address the increased shortage in school buildings. The program promoted prefabricated, light timber designs with a time and cost efficient construction process. In recent years, the Permanent Modular

School Buildings Programme (PMSBP) by the Victorian School Building Authority aims to replace old school buildings with newly built modular classroom buildings in 100 schools in Victoria [7,31]. In Spain, over 200 public schools have been constructed using prefabricated processes to address the shortage in school infrastructure. An analysis comparing three concrete, steel and timber prefabricated school buildings to a conventional structure found the life-cycle impacts of prefabricated timber schools were lowest [15].

2.2. Private Timber School Buildings

Outside of government-led initiatives, schools in the UK have independently seen an increased application of engineered timber as a structural material (Figure 2). Such applications cover a high diversity of state and private schools in terms of programme and scale, new structures and refurbishments, as well as primary and secondary institutions. In recognition of their environmental stewardship and architectural excellence, a majority of these school buildings have been extensively publicised and received prestigious awards, including the RIBA National Education Award and BREEAM "Excellence" certificate. Outside of the UK, numerous projects in mainland Europe have demonstrated the use of engineered timber for schools.

Figure 2. Examples of Engineered timber schools buildings in the UK: (**a**) Ickburgh primary school, Avanti Architects/Eurban (**b**) Stephen Perse Foundation, Chadwick Dryer Clarke Architects/Smith & Wallwork Engineers (**c**) Ralph Allen School, Feilden Fowles Architects, Eurban (**d**) Holy cross primary school, Cullinan Studio/Smith & Wallwork Engineers, Image credit: Paul Raftery.

At an international level, a particularly celebrated example of an engineered timber educational building is the Vrin School Multi-purpose hall, designed by architect Gion Caminada and structural engineer Jürg Conzett, which forms part of a school extension that is available for use by the wider community [32]. Moreover, Storaenso, a timber manufacturing company in Finland, has identified the benefits of prefabricated, modular school buildings, by developing appropriate design and manufacturing models [33]. Similarly in the United States, the Gen7 Modular programme by American Modular Systems is a private prefabricated school construction initiative focusing on re-usability [34]. In this system, modules are intended to be removed, relocated and reused after they have served their initial purpose for 15–20 years.

The precedent study previously presented has highlighted how government led initiatives have evolved over the years to deliver school buildings in a time and cost efficient manner. While the benefits of prefabrication and modular construction have been exploited over the past decades, it is only recently that the focus of such initiatives has shifted to include sustainability and whole-life emissions. Engineered timber construction combines the benefits of prefabricated construction with carbon sequestration and low whole-life emissions and can therefore help to address this challenge. In order to develop a strategy to promote engineered timber construction for school buildings, it is essential to identify the challenges and opportunities associated with it.

3. Challenges and Opportunities of a Public Engineered Timber School Programme

3.1. Challenges

3.1.1. Contractual Framework of Engineered Timber Projects

The stakeholders involved in a prefabricated engineered timber project may vary significantly when compared to projects using conventional construction materials, such as concrete or steel. The lack of well-established methodology and guidance on the structural analysis of some engineered timber materials renders specialist knowledge and skills necessary for the delivery of a prefabricated engineered timber project. Furthermore, specialist computational skills and knowledge of manufacturing procedures are required for the efficient planning and optimisation of the fabrication and assembly process. The formal education of architects and civil engineers may not incorporate such training or skill development in timber engineering. As a result, the inclusion of a timber engineer or specialist is often required for the successful delivery of a prefabricated engineered timber project. Additionally, input from engineered timber suppliers may be critical in early-stage design to ensure a feasible and practical design given manufacturing and logistics constraints. At the same time, it can ensure a uninterrupted procurement process Limitations in existing contractual frameworks for such projects may impede the timely involvement of such specialists and pose challenges to the clear distribution of legal liabilities between stakeholders [35].

3.1.2. Labour Supply

The UK faces significant labour shortages in the construction sector [36]. These shortages are seen to inhibit growth of this sector, creating challenges in meeting construction demand. Brexit has exacerbated these labour shortages by limiting the immigration of workers who have typically filled a large number of constructor sector roles in the UK [37]. These labour shortages could pose significant challenges to delivering the required number of school buildings using conventional construction methods within the government's timeframe and budget targets.

3.2. Opportunities

3.2.1. Carbon Sequestration

Composed primarily of cellulose, hemicellulose and lignin, timber consists of approximately 50% atmospheric carbon by mass, sequestered through photosynthesis over the lifetime of the tree from which it was harvested [18]. Thus, every tonne of timber contains sequestered carbon equivalent to 1.8 tonnes of atmospheric CO_2. Recent studies have highlighted the significant potential for buildings built primarily using timber to act as a global "carbon sink", safely storing atmospheric carbon for the life-span of buildings (50–60 years) [38]. At the end-of-life of such structures, timber elements may be reused, recycled, or burned as biomass fuel. When combined with sustainable management of forests (replanting, active management), such a construction approach could facilitate the transfer of significant volumes of atmospheric carbon into the built environment for long-term storage in a cost-effective manner [39,40].

3.2.2. School Program Standardisation

The embedded repetitiveness in the programme requirements of schools renders off-site manufacturing an appropriate construction method for this building type. Government-led initiatives have enabled the identification of the different type of activities and programmes carried out in a school building and the generation of a catalogue of the respective room types to accommodate them [41]. Furthermore, the spatial requirements linked to each activity have been defined, depending on the size of the school and the number of pupils, leading to a standardisation of the complete school design programme [42,43]. These guidelines are freely available online, promoting the adoption of modular designs, standardisation and off-site manufacturing where possible [41–43]. As of 2019, the UK Government has also committed to a "presumption in favour" of off-site construction for procurement of all new buildings by all key government departments [13].

Taking advantage of the opportunities that the standardisation of the school programme offers, a number of interactive computational tools have been developed in recent years to facilitate the design of modular school buildings. Available through digital interfaces, these tools allow users to explore school footprints based on programme requirements, available prefabricated timber components while complying with DfE guidelines for standardised off-site construction [44]. A digital app for the design of prefabricated school buildings in the UK was developed, as part of an Innovate UK funded project [45]. Developed in an intuitive and user-friendly environment, the application allows users, as young as primary pupils, to generate school designs in the UK, following the guidelines and adjacencies prescribed by guidelines of the Department of Education. It is important to note that the design process is agnostic of construction methodology and material. Sunesis is another private initiative offering a modular, off-site construction of primary school buildings. Apart from a set of fixed sizes and layouts, a kit of 77 components has been developed that can be configured to meet project-specific needs [46]. Although not explicitly intended for school buildings, Dataholz is a web-app containing tectonic components for timber structures, i.e., floor, wall, roof, internal, external, compartments, etc. that comply with engineered timber design regulations [47].

3.2.3. Design for Manufacturing and Assembly (DfMA)

In panelised prefabricated construction, building components arrive on site in the form of panels and are then assembled and connected to form the final structure. One of the main drivers of the assembly time and cost is the number of crane lifts required to place structural elements in position. This number can be minimised by the consideration of project-specific requirements and a detailed planning of the assembly process. Engineered timber components that arrive flat- packed on site can be assembled into structural systems on site, which are then placed in position, reducing the overall number of crane lifts required. At the same time, the principles of Design for Manufacturing and Assembly (DfMA) enable the evaluation of alternative ways of detailing and manufacturing components, which has a direct impact on their transportation and assembly. The arrangement of structural components on engineered timber panels can also be optimised to minimise waste.

DfMA can make substantial contributions to the acceleration of the construction process. This is particularly critical in the context of educational buildings, since the tight assembly processes linked to engineered timber construction can be accommodated within school holidays, therefore minimising disruptions to the school programme, which remains in use throughout [48]. Figure 3 demonstrates the timber assembly time required for different engineered timber school buildings in relation to the scale of the project. Despite the high variety in school sizes covered, the assembly time is limited from a few days to a few weeks. In the case of the school extension projects presented, this time is accommodated within the school summer holiday period, without causing any disruption to the school programme. An interesting observation of the outcomes is the fact that the assembly time does not scale linearly with the school area, becoming apparently more efficient in large-scale structures.

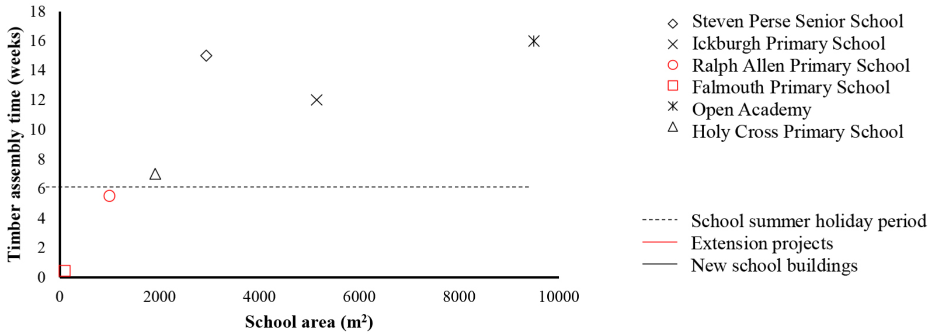

Figure 3. The relationship between the time required for construction and the area of the case-studies analysed. The duration of the summer holidays is plotted, demonstrating that the construction time of the school extension projects could be incorporated within the break [49].

4. Strategy to Achieve a Future UK Prefabricated Engineered Timber Schools Programme

Building on the challenges and opportunities identified, a comprehensive strategy is proposed to address existing obstacles and promote the adoption of engineered timber construction for government-procured school buildings.

4.1. Policy

The construction process of engineered timber structures requires the early involvement of all stakeholders. While advanced coordination and collaboration are required upfront, this method increases the certainty during the construction and procurement process, mitigating the risk and minimising any contingencies that may arise. Policymakers should therefore facilitate this process by establishing contractual and legal forms that are appropriate for engineered timber and facilitate such collaborative and coordinated projects. An important step towards this direction has been the revision of the RIBA plan of work, following feedback from industry [50]. These revisions aim to form a new sustainable project strategy. In addition, recommendations and guidance provided aim to address the changing nature of the commissioning, design and construction team and improve procurement, project coordination and construction.

4.2. Skills Training

Given the significant skilled labour shortage in the construction sector and the relatively small size of the prefabricated timber construction industry in the UK, the government may have also have a role to play in the funding of and coordination with industry bodies which deliver skills training programmes for workers across the supply chain of prefabricated engineered timber construction. Such training could build on existing design expertise in engineered timber construction in the UK, and should include both design and engineering training, as well as any skills training required for fabricators, including the use of digital fabrication technologies. Long-term measures to address this challenge include the inclusion of appropriate skill development and training in the formal education of architects and civil engineers.

4.3. Guidance

4.3.1. Design Tools for Engineered Timber School Buildings

The government plays an essential role in developing design guidance and tools that strike a balance between the need to create healthy and engaging educational environments and achieve savings in the time, cost and life-cycle impact of new building structures. The automation of the construction process of prefabricated engineered timber lends itself well to this context, allowing for the development of a universal set of interchangeable modular building elements, and the flexibility for designers and manufacturers to develop innovative and expressive context-appropriate solutions for school designs with a low whole-life impact. It is therefore essential that any design and construction guidance developed enables and facilitates the consideration of engineered timber as a construction material.

4.3.2. Material-Specific Cost Indicator

Off-site manufacturing is embedded in the construction process of engineered timber buildings. Nevertheless, the variety of different types of prefabrication available renders the selection of the prefabrication method a critical factor in the assessment of the construction complexity and cost of an engineered timber project. While volumetric prefabrication offers substantial time-savings, it can result in higher material use, due to redundancy of structural members where modules adjoin. In contrast, panelised prefabrication may require slightly longer time for assembly but may have higher efficiencies in transportation and material volume. It therefore becomes evident that the complexity of the construction process of engineered timber projects is not fully captured by cost indicators used with conventional construction materials, such as floor area cost (£/m^2) or material volume cost (£/m^3). In the case of engineered timber projects, such indicators should be linked with the type of prefabrication used in order to provide a comprehensive image of the assembly process. This can then act as a guide for the valid comparative assessment of the time and cost required for different construction materials in early stages of the project development.

4.4. Prefabricated Engineered Timber Industry in the UK

While the recommendations presented form measures that can be applied immediately, the uptake of engineered timber construction for school buildings can trigger longterm impact on UK industry and it can therefore enable the adoption of additional steps in the future. Engineered timber structures built in the UK typically use finished engineered timber products sourced from suppliers in countries with abundant sustainably managed forests and established structural timber industries, such as the Scandinavian and Central European countries [51]. Given the UK's relatively modest domestic timber resources and primary timber processing capacity, it is unlikely that a completely domestic engineered timber supply chain is likely to be scalable to the capacity needed to meet construction demands in the UK.

Beyond the immediate benefits of using prefabricated engineered timber for schools, however, the opportunity exists for the procurement of these structures to stimulate the growth of tertiary engineered timber processing businesses in the UK. Such businesses could also provide long-term economic benefits to UK communities through the provision of long-term employment with safer, healthier working conditions than those currently afforded by many conventional construction sector jobs. If distributed regionally, such businesses could also contribute to the creation of employment opportunities in areas outside of major urban centres. This could form part of a longterm strategy to develop a timber industry in the UK and further research will be needed to identify the specific location and time of its deployment.

5. Benefits from a Future UK Prefabricated Engineered Timber Schools Programme

5.1. Environmental—Carbon Storage

The use of prefabricated engineered timber in new school buildings in the UK could help to meet the demand for new schools while meeting time, cost and sustainability requirements. In addition, engineered timber school buildings have the potential to act as carbon sinks, storing carbon within their building components. Assuming a gross school building area requirement per secondary school student of 7.10–7.85 m^2 [42] and 186 kg CO_2 sequestered in structural timber elements per square meter of building floor area [38], the construction of new school buildings to provide 120,000 additional secondary school places by 2024 would result in the long-term sequestration of approximately 0.17 megatonnes of CO_2. For context, the UK's annual CO_2-equivalent emissions in 2019 were approximately 414 megatonnes [52].

Assuming roughly 0.25 m^3 of timber required for m^2 of building floor area, this construction is associated with the use of approximately 225,000 m^3 of timber [38,53]. For context, in 2020 the UK imported approximately 7.2 million m^3 of sawn timber [54]. For further perspective, Europe produced approximately 108 million m^3 of sawn timber in 2019 [55], suggesting that increased construction of schools using engineered timber in place of other structural materials in the UK is unlikely to place significant strain on available timber resources barring substantial changes in timber consumption patterns in Europe.

The process of constructing buildings using timber has also been demonstrated to have lower associated greenhouse gas emissions than would be produced using conventional construction materials, steel and concrete [56]. These characteristics make timber highly competitive, when compared to conventional construction materials, such as reinforced concrete and steel, with regard to the construction of new buildings within the limits of the UK's sustainability targets. More precisely, the carbon storage of timber as a construction material is recognised as a key feature of private engineered timber school buildings and it is considered as a critical factor contributing to the sustainability of the overall project. The extent of this contribution is often quantified either as the total tonnes of CO_2 captured or the volume of timber used in the structure, as shown in Table 2.

Table 2. The timber volume and captured carbon of the case-studies analysed highlight the environmental benefits of engineered timber as a construction material. The sequestered carbon is calculated as a factor of the timber volume [57].

School Building	Timber Volume (m^3)	CO_2 Captured (t)
Steven Perse Senior School [58]	850	765
William Perkin High School [59]	3800	3420
Open Academy [60]	3095	2785.5
Falmouth Primary School [61]	67	60.3
Lauriston Primary School [48]	651	585.9
City Academy [62]	3078	2770.2
Hatcham Temple Grove Primary [63]	13.8	12.42
Red Lodge Primary School [64]	586	527.4

5.2. Social-Physiological and Mental Health Benefits of Timber

In addition to its sustainability benefits, the use of exposed timber in structures is likely to have physiological and mental health benefits for building occupants. Spaces with exposed timber elements are found to increase the number of social interactions between individuals and improve the emotional state of users [65,66]. In educational settings in particular, the classroom design can have a high impact on the learning process of students [67]. Classrooms with exposed timber have been shown to result in reduced heart rate and perceived levels of stress in students compared to classrooms where other materials are used [68]. Procuring engineered timber school building can therefore have a long-lasting positive impact on the education and performance of students.

5.3. Economical-Prefabricated Engineered Timber Industry in the UK

As previously described, a generalised adoption of engineered timber in construction could trigger the development of a UK engineered timber industry through the establishing of digital manufacturing centres for engineered timber building components. In the production of CLT panels for use in construction, tertiary processing (machining of door and window cutouts, connection details, and further processing) accounts for 30–40% of the total value of the final product (based on personal communication with practising structural engineers in the UK). However, these processing operations remain a manufacturing bottleneck even in locations with abundant forest resources and primary processing capacity. Establishing manufacturing businesses in the UK to perform tertiary processing operations to engineered timber elements for use in construction could capture these "added-value" revenues for UK businesses and workers. Assuming a cost of £240/m^2 of floor area for typical CLT construction (corresponding to an estimate of 2013 costs [69]) and a gross building area requirement per secondary school student of 7.10–7.85 m^2 per student [42], UK secondary engineered timber processing businesses could receive a gross revenue of £61–90 million through the construction of schools to provide 120,000 new school places. It should be noted that the cost of timber has increased substantially in 2020 and 2021, potentially affecting the results of any cost analysis of increased timber construction of schools in the UK.

Performing tertiary engineered timber processing operations domestically could also potentially result in reductions in the life-cycle impact of engineered timber structures built in the UK. Finished engineered timber elements are typically transported by lorry, whereas raw engineered timber elements are typically transported by rail. The energy consumption and greenhouse gas emissions associated with rail transport are estimated at 0.18 MJ/tkm and 0.013 $kgCO_2$/tkm, whereas the respective values for transport by lorry are 1.1–0.71–2.2 MJ/tkm and 0.05–0.16 $kgCO_2eq$/tkm [70]. By performing tertiary processing operations on engineered timber elements closer to their ultimate destination, reductions could be made in the energy consumption and greenhouse gas emissions associated with the construction of engineered timber structures, by reducing the transport distance required by lorry as opposed to rail.

6. Application of the Proposed Strategy in Different Contexts

The proposed strategy for a government procured engineered timber school program was developed taking into account UK specific parameters and constraints. Nevertheless, the standardisation of educational design requirements and the sustainability of engineered timber as a construction material show the potential of its application in different contexts at an international level. The strategy can be adapted to respond to the requirements of different countries, depending on their context-specific properties. More precisely, this strategy was developed taking into consideration that the UK is currently importing engineered timber products from countries with abundant sustainably managed forests and established engineered timber industries. Countries with similarly modest domestic timber resources and with access to finished engineered timber products could adopt the strategy as presented. On the other hand, countries with an existing timber industry could only adopt the short-term measures of the strategy that refer to policy, training and guidance. This would enable them to facilitate the generalised uptake of engineered timber as a construction material through both government-procured and private projects. Finally, countries that do not have a domestic timber supply and the import of engineered timber products not efficient in terms of emissions or cost should explore the possibility of using alternative natural construction materials that are available and offer a sustainable and efficient construction process.

Moreover, certain countries have already started implementing aspects of the proposed strategy. France has published guidance for wood construction for multi-family housing and requires all public buildings to be made 50% from wood or other natural construction materials [71,72]. This is further supported by the establishment of institutions for the development of the appropriate skills and training for engineers, such as ENSTIB, which educates future timber engineers enstib. In this case, the strategy can be further adapted to exclude measures that are already in place. These findings are summarized in Figure 4.

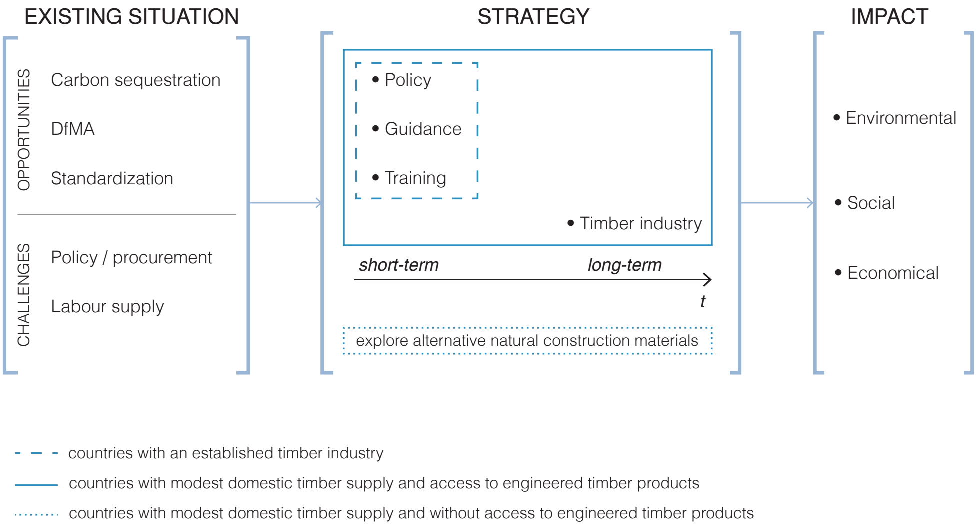

Figure 4. An overview of the developed strategy and how it can be adapted for its application in counties with different requirements and needs.

7. Conclusions

This paper has presented a novel strategy that will enable the adoption of engineered timber construction for the delivery of government-procured school buildings in the UK. The challenges and opportunities of developing this approach are identified and a strategy is developed that proposes specific policy measures, professional and academic training requirements as well as guidance needed to achieve this. The environmental, social and economical benefits of addressing current shortages in school places with an engineered timber school programme are then outlined, including the possibility of storing 414 megatonnes of carbon, improving students' performance and wellbeing, as well as triggering the development of a timber manufacturing industry in the UK that could support domestic economic development, bringing an income of £61–90 million. Methods for the adoption of this strategy in different countries are then presented, offering context-specific recommendations. The use of engineered timber construction is hence promoted as a sustainable and efficient method to address pressing challenges in educational infrastructure.

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