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A framework for assessing the environmental benefits of mass timber construction

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Abstract

The construction industry represents one of the most significant contributors to human-induced environmental damage. Many of the negative consequences on the environment result from the extraction, processing and manufacture of construction materials and components. This includes the depletion of raw material, energy and water resources; loss of habitats; contamination of water and soil; reduced air quality; and climate change. The production of some of the most common construction materials, such as concrete, steel, glass and aluminum are of most critical concern. There is a growing awareness of the need for a greater use of renewable materials that not only reduce resource depletion, but also address the range of other environmental issues. Cellulose-based materials, such as timber and straw are a commonly used renewable alternative. While timber has been used in construction for many centuries, there has been a recent resurgence in the use of timber as a replacement for traditional concrete and steel structures, particularly in response to these pressing environmental imperatives. Mass timber construction (MTC) is seen as a potentially viable alternative for dealing with these issues while at the same time meeting the demands of modern buildings, such as increasing height, speed of construction and fire resistance. Most existing research on MTC has been centered on its structural performance and fire resistance. There is a general lack of understanding of how this form of construction performs from an environmental perspective, which is critical given this is considered as one of its main strengths. This study establishes a framework for assessing the environmental benefits of MTC. The aim is to provide a streamlined approach to enable key building project stakeholders to assess the potential for MTC to provide environmental benefits over traditional construction methods in a particular building project. This can provide useful guidance for decision-making in relation to the use of MTC.

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1. Introduction

The construction industry is responsible, predominately through the construction and operation of buildings, for around 40% of global energy use, 25% of global water consumption, and around 30% of global greenhouse gas emissions (GHGE) [1]. These resource demands and emissions result in considerable effects on the environment. A large amount of effort has been placed on reducing the environmental effects associated with the operation of buildings. There has been less, but an increasing focus on the environmental effects associated with material manufacturing and construction activities. Conventional materials used in the construction industry, such as concrete, steel and glass are of most concern as their production processes are more often than not, raw material, energy, water and GHGE intensive. For example, the production of cement is responsible for 3% of global CO₂ emissions attributable to human activities [2].

Significant improvements have been made to the environmental performance of materials like concrete and steel. Substituting a percentage of the raw materials used to produce concrete with recycled material, for example, has been shown to lower its environmental effects. Other studies suggest different approaches, such as Damtoft [2] who indicates that the greatest potential to reduce GHGE associated with cement production, the most emissions intensive component of concrete, is to replace conventional carbon-based fuel during production, with alternative fuels such as biomass. Also, researchers have suggested dematerialisation by enhancing concrete performance in order to reduce the volume of concrete needed. Such an approach could lead to a reduction in GHGE of up to 30% [3]. Despite these improvements, materials such as concrete are still manufactured using non-renewable raw materials. This means that eventually these raw materials will not be available to be used to manufacture construction materials, like concrete, in their current form.

With this in mind, alternative means of construction will eventually need to be found to replace these more conventional materials. This is an environmental imperative more than anything else as steel and concrete have proven to be far superior to any other material for large-scale construction projects across almost every other performance criteria, such as cost, fire resistance and structural adequacy, to mention but a few. In order to address the unsustainable nature of current building construction there is a growing understanding that buildings must use a much higher proportion of renewable materials. This, coupled with renewable fuel sources, smart design and quality of execution will help improve the sustainability of building construction.

Cellulose materials such as bamboo and timber are potential alternatives that are renewable. Cellulose materials have been used in construction for many centuries but are less common in larger buildings due to concerns over structural performance, durability, fire resistance and acoustics. These buildings tend to be constructed of steel and concrete due to their suitability and proven performance in medium to high-rise construction, and the economies possible at this scale make these materials even more competitive.

Mass timber construction, or MTC, is being used in an increasing number of building projects as a replacement for concrete and steel. MTC comes as either a honeycomb system using primarily cross-laminated timber (CLT), or as post and beam construction using a mix of CLT, glue laminated timber (Glulam) and laminated veneer lumber (LVL). There has been a sharp increase in the use of MTC in recent years. In 2003 there was only one CLT manufacturer in Europe producing around 4,000 cubic metres per year. Now there are around 50 CLT manufacturers globally with a combined production volume of about one million cubic metres expected this year [4]. There has been a significant amount of work into the structural, acoustic and fire performance of MTC, in particular. Much less is understood about how MTC performs from an environmental perspective. With one of the most common claims for justifying the use of timber being its environmental benefits, this is surprising. In order for design professionals to make more informed choices when it comes to the use of MTC, a more detailed understanding of how it performs from an environmental perspective is needed.

1.1. Aim

The aim of this study is to identify the key factors affecting the environmental performance of MTC and to establish a framework that can be used to assess the environmental benefits of MTC within a building project.

2. Background

Construction materials have a significant influence on the environmental performance of a building. While substantial improvements have been made to how buildings perform, there is still considerable potential to improve their environmental performance, especially by careful selection of materials. The influence of materials on building operation, such as energy use, is well documented and an integral part of best practice building design. The consideration of material production in improving building environmental performance is less frequently considered. An increasing number of studies (inter alia [5]), show that material production can have an even greater influence on building environmental performance than building operation. Investigating and selecting alternative modes of construction that can help to reduce material production-related environmental effects is therefore critical.

More than a decade of research has attempted to demonstrate the environmental benefits of MTC buildings, generally by comparing the performance of a MTC building with an equivalent concrete building [6]. Oliver [7] showed a 14-31% reduction in GHGE and Durlinger et al. [8], using a case study of the Australian MTC building, 'Forté', showed a reduction in global warming potential (GWP) of 13%-22%, compared to a building of similar design using concrete. A recent study by Liu et al. [9] compares a building constructed with conventional in-situ concrete with one using CLT. Both buildings are of the same dimensions, functionality, layout and orientation. The only change is a slight adaptation of the sizing of the structure to accommodate the load capacity of CLT. The study demonstrated considerable savings in energy use and GHGE for the operational phase of the CLT building.

However, many previous studies suffer from significant limitations due mainly to unavailability of specific information from MTC manufacturers. These studies could be considered inconclusive in their quantification of the environmental benefits of MTC due to a lack of specific information on the timber products analysed and the use of flawed assessment techniques. In particular the use of process analysis to quantify resource requirements and emissions associated with the manufacturing process results in the exclusion of many of the indirect, yet potentially resource and emissions intensive processes, often too difficult to collect using this approach [10].

2.1. Assessing the environmental benefits of MTC

In order to assess the environmental performance associated with the use of particular building materials, tools such as life cycle assessment (LCA) are often used [11]. Environmental Product Declarations (EPDs) and other databases, describing the resource demands (such as energy, water and raw materials) and outputs (waste, pollution, emissions, products) associated with the provision of a product or service often form the basis of LCA studies.

While LCA provides an insight into the environmental performance of a product at a particular point in time, it often provides little guidance as to the broad range of factors that are likely to affect this performance throughout its life, such as labour intensity, equipment intensity, speed of construction and degree of prefabrication. Unless all factors are considered, it is not likely that the true benefits of the use of a material like MTC will be known. Also, LCA studies generally relate to a particular context or case and the extrapolation of this to other contexts or cases can be problematic. For example, an LCA study of the use of MTC will often relate to a particular building with an assumed life, using a MTC material such as CLT with an assumed service life. How does the environmental benefit of the use of the CLT change should a different building or material life be assumed, or a different location or building type be required? A sensitivity analysis could be used to answer some of these questions, but this just requires time and money, often beyond the scope of a project budget. LCA studies are already very time intensive and costly to conduct. Most building projects simply do not have the resources to be able to conduct such studies

and so quantifying the true benefits of the use of MTC on a particular project can be extremely difficult. This is where detailed guidance for decision-makers is needed. An understanding of the critical factors to consider in designing a MTC building to maximise its environmental performance can help optimise the environmental benefits of a project that may not have been realised otherwise without the use of a detailed LCA study.

Despite some of the limitations of LCA studies, there is still important information about some of the critical factors affecting the environmental performance of MTC that can be gleaned from previous and new LCA studies of this form of construction. For example, LCA studies can help identify the individual processes (such as timber milling or drying) and their associated environmental loadings related to the production of MTC materials, thus providing guidance on some of the critical factors to be considered. Other tools, such as input-output analysis can also be useful (and often critical) in identifying the broad range of processes and environmental loadings associated with MTC. As MTC is a relative recent approach to construction, there is still a lack of comprehensive information on how MTC performs from an environmental perspective compared to more conventional construction alternatives, including guidance to help inform the decision of whether or not to use MTC on a particular project.

3. Framework for assessing the environmental benefits of mass timber construction

This section details the steps involved in a proposed framework to assist architects and other construction industry professionals to quickly ascertain the potential environmental benefits that may be attributed to use of MTC on a specific construction project, compared to the traditional alternative (typically concrete and/or steel construction). The framework encompasses the steps outlined in Fig. 1, described in more detail below.

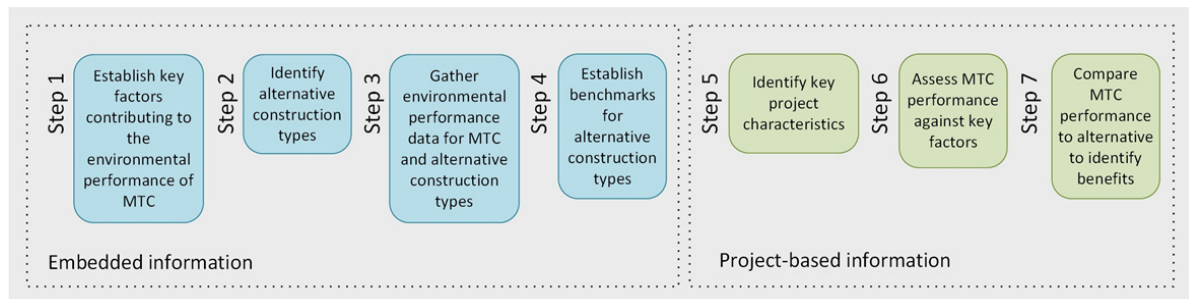


Fig. 1. Framework for assessing the environmental benefits of MTC.

Step 1: Establish key factors contributing to the environmental performance of MTC

An understanding of the critical factors that affect the environmental performance of MTC is essential in order to help ensure that the greatest benefits of the use of the material are being achieved. In order to establish the factors that affect the environmental performance of MTC, it is first necessary to identify the range of environmental effects associated with the production and use of timber in the form of MTC. Previous LCA studies of MTC are a useful resource for identifying these effects, which include climate change, resource depletion (energy, water, minerals), land use, waste production, eutrophication, acidification, smog, ozone depletion, ecotoxicity and human toxicity.

Based on a number of previous studies on the environmental performance of MTC, as well as other LCA studies, Table 1 lists the key factors affecting the environmental performance and/or benefits of MTC, grouped according to the life cycle stages of EN 15978 [12].

Table 1. Factors affecting the environmental performance/benefits of MTC.

Building life cycle stage		Factors affecting environmental performance/benefits of MTC
Product	A1 Raw material supply	Biodiversity conservation
		Carbon sequestration rate
		Forest management practices
		Harvesting practices (fuel and machinery types)
		Timber type
	A2 Transport	Road type and land topography
		Timber density
	A3 Manufacturing	Transport distance, mode and fuel type
		Manufacturing processes (fuel and machinery types)
		Packaging
		Roundwood conversion efficiency
Scale of production		
	Storage	
Construction process	A4 Transport	MTC material size
		Transport distance, mode and fuel type
	A5 Construction-installation process	Construction time/speed
		Equipment and fuel type
		Extent of MTC for project
		Extent of processing of MTC materials
		Regulation compliance (fire, acoustics)
	Site access	
Use	B1 Use	Indoor environment quality (IEQ), release of volatile organic compounds (VOCs), formaldehydes etc.
	B2 Maintenance	Maintenance regime
		Quantity and type of materials required
	B3 Repair	Potential for water damage and insect or fungal attack
		Frequency of repair
	B4 Replacement	Quantity and type of materials removed and required for repair
		Service life of materials
	B5 Refurbishment	Quantity and type of materials removed and required for replacement
Frequency of refurbishment		
B6 Operational energy use	Quantity, type and source of materials required for refurbishment	
	Thermal performance	
B7 Operational water use	Thermal performance	
End-of-life	C1 De-construction demolition	Deconstruction time/speed
		Equipment and fuel type
	C2 Transport	Transport distance, mode and fuel type
	C3 Waste processing	Quantity and type of materials
		Waste treatment type and process (reuse, recycling, disposal, energy recovery)
	C4 Disposal	Disposal site management practices
		Disposal type (landfill, incineration, neutralisation)
Equipment and fuel type		

NB. This list is not exhaustive and further factors may be identified.

Step 2: Identify alternative construction types

In order to establish the benefits of MTC, it must be compared to the most likely alternative construction type. This step involves identifying the range of possible alternative construction types and will usually be performed prior to the assessment of a particular project. It will inform the data that needs to be gathered in Step 3 and the benchmarks to be established in Step 4, providing a range of baseline alternatives to select from for comparison to

MTC. These alternative construction types will include the most typical forms of construction within a particular location/region and may also include common variations to these, such as column grid, structural material mix, and construction method.

Step 3: Gather environmental performance data for MTC and alternative construction types

In order to establish the environmental benefits of MTC compared to alternative construction types, information on the resource requirements and waste production and emissions associated with its various life cycle stages is needed. Environmental benefits from the use of MTC may be a reduction in energy use, GHGE and waste production, for example. Environmental performance is most often established with the use of LCA. As the point of this framework is to minimise the time and costs involved in understanding how MTC performs, conducting an LCA for each project is what the use of the framework aims to avoid. This step therefore aims to gather generic environmental performance data for both MTC and the range of alternative construction types (materials and whole buildings), to be embedded into the framework. Project specific characteristics identified in Step 5 can then be used to customise this assessment for a particular project. Published LCAs and EPDs provide a useful source for this information and data on individual processes, such as transportation, processing, manufacturing and construction, can usually be easily ascertained.

Step 4: Establish benchmarks for alternative construction types

Benchmarks are required to provide a baseline against which to compare the performance, and establish the benefits, of MTC. These will be based on the LCA data collected in Step 3 as well as building performance benchmark studies [e.g. 13, 14]. Benchmarks should be established for as many of the factors identified in Step 1 as possible. These will form default values for each of the factors within each life cycle stage (e.g. transport type, fuel and distance), which can then be adjusted according to more specific project characteristics (Step 5).

Step 5: Identify key project characteristics

The extent of information available on the project-specific benefits from the use of MTC will depend largely on the amount of information available about the specific project characteristics. The more details about the construction project that are known, the more reliable the assessment of the benefits of the use of MTC will be. The most detailed information about a project is not known until later in the project life cycle, when there is also less need for information to inform critical decisions, such as the choice of structural material. Despite the lack of information that is likely to be available when a decision about the use of MTC needs to be made, some information is often known and this can be used as part of the assessment. This may include the location of the project, building size, building design life, and jurisdiction-specific regulatory requirements.

Step 6: Assess MTC performance against key factors

This step involves assessing the project-specific performance of MTC against the factors, life cycle stages and environmental criteria identified as being important. The assessment is based on a life cycle approach, using the EN 15978 building life cycle system boundary [12]. For each of the key factors (Table 1), values must be selected from either a predefined list or by manually entering them. This may include anything from the timber used for MTC production to the service life of the material in use. For example, a user may select a particular source for the timber (affecting performance relating to stages A1-A4), which would populate the assessment with information relating to a particular location of manufacture, based on data gathered in Step 3. This would, for example, present a default transport mode and calculate transport distance based on project location. Each factor is then assessed against the relevant life cycle stages and environmental criteria. Values for the amount of water used, waste produced, GHGE released etc. will be calculated based on project-specific characteristics. Factors won't necessarily have an influence on the environmental performance of MTC at every life cycle stage, nor for every environmental criteria. Fig. 2 shows the scope of the assessment process.

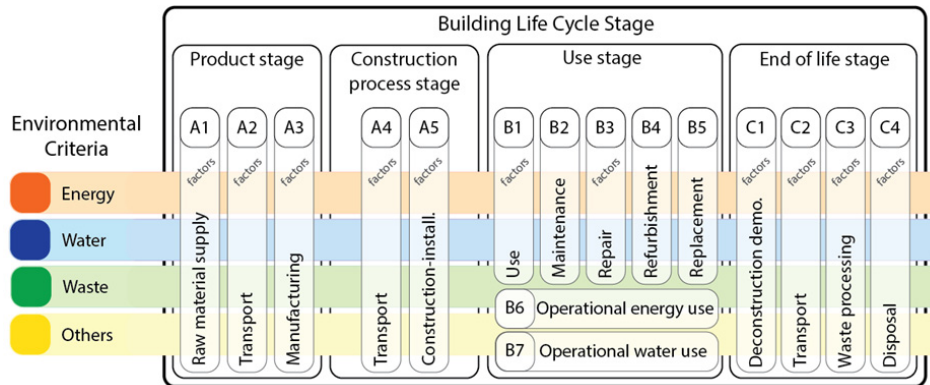


Fig. 2. Scope of the process for assessing the environmental performance of MTC.

Step 7: Compare MTC performance to alternative to identify benefits

Firstly, the most likely alternative construction type will need to be selected from the range of possible alternatives identified in Step 2. For the alternative construction type, default values for each of the factors affecting the environmental performance of MTC will be populated into the comparison. Most of these values will be editable by the user should they not reflect reality (e.g. different material source, service life, transport mode etc.). Obviously, the more reflective of reality the better as an underestimation of the environmental effects of the alternative construction type may overestimated the benefits attributable to the use of MTC and vice versa. The strength of the framework however is that it streamlines the assessment by using pre-existing data. However, this strength needs to be balanced with the potential non-representativeness of this data. Performance of MTC against the selected alternative construction type can then be compared. There is a wide range of potential comparisons that could be made, from an individual environmental criteria for one life cycle stage (e.g. energy use for transport of materials to site) or ideally for a broad range of environmental criteria across the full building life cycle. The benefits of MTC relate to the alternative construction type, which is represented as a baseline (0). Example outputs are shown in Fig. 3. Fig. 3d combines results across all life cycle stages and provides a normalised score of the benefits of MTC across each environmental criteria and in total, based on user weightings.

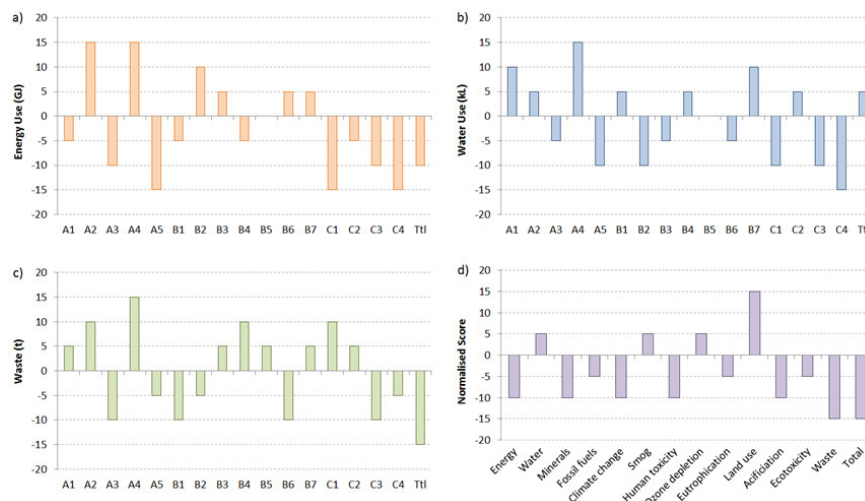


Fig. 3. Possible framework outputs - benefits of MTC across life cycle stages and environmental criteria, compared to alternative (baseline).

A strength of the framework will be the ability for a user to adjust particular variables along a sliding scale and dynamically see the effect that these changes have on the benefits of using MTC. A user may move sliders to the right or left to adjust the transport type and distance, for example. As the sliders move towards a longer transport distance and less efficient transport mode the benefits of using MTC will reduce, dynamically shown in the graphical outputs.

4. Discussion and conclusion

The use of MTC is growing, but it is still used in only a very small proportion of construction projects. Part of the reason for this may be due to a lack of a detailed understanding about how it performs. While there is a common belief that MTC will provide environmental benefits, there is no clear evidence that this is the case. It is even less likely that the benefits from the use of MTC on individual projects are known. Providing an approach that allows designers to assess the potential environmental benefits of using MTC on a building project may instill a greater level of confidence in its use. This has the potential to lead to an increase in the uptake of MTC, which in turn may lead to more rapid GHGE reductions and the achievement of global environmental sustainability goals and targets. The framework described in this paper is a critical step towards exploring whether this is possible. Without a way of quantifying the environmental performance of MTC, there is no way of knowing whether or not it provides environmental benefits compared to more traditional construction methods.

This paper examines existing LCAs of MTC in order to identify the key factors affecting the environmental performance of MTC. It is then proposed that these key factors are used to assess the benefits associated with the use of MTC, according to a life cycle-based assessment framework. This framework is guided by the European Standard EN 15978 separating the building life cycle into four phases: product, construction process, use and end-of-life. The innovation of this framework is that it relies on data and findings from previous research related to MTC to help streamline the decision-making process associated with the choice of MTC as a potential construction solution. However, rather than relying solely on previous LCA studies to help inform the choice of MTC, this framework enables a more project-specific assessment, allowing a designer to adjust variables for some of the key factors affecting the environmental performance of MTC based on known project characteristics.

A potential limitation in the use of this framework is where embedded data does not reflect specific project requirements, such as the source of the timber, manufacturing processes etc.. If no more reliable project-specific information is available, the assessment of benefits may be highly unreliable. Also, while environmental considerations are important, there are other aspects of using MTC that will inevitably need to be considered in any decision to use this form of construction, or any for that matter. These include, but are not limited to, cost, access to skilled labour, and material availability. The next stage of this work involves the development and testing of the framework on both existing and proposed MTC building projects. This will help inform the establishment of guidelines for the use of this framework in building design decision-making, centered on maximising the environmental benefits of the use of MTC.

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