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ENVIRONMENTAL LIFE CYCLE ASSESSMENT OF MULTIPLY

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INTRODUCTION

MultiPly is a collaborationn of the American Hardwood Export Council, Waugh Thistleton Architects, and the London Design Festival to explore a new, more sustainable way of building, bringing together modular design with American tulipwood Cross Laminated Timber (CLT), a carbon-negative material.

The structure comprises 17 interconnecting modules, made from a total of 102 60mm and 100mm thick x 2.6m long CLT panels finger-jointed by Glenalmond Timber in Scotland and fabricated at the Construction Scotland Innovation Centre (CSIC). The structure was finished and installed by Stage One based in Yorkshire.

The Life Cycle Assessment (LCA) quantifies the environmental impacts of *MultiPly* covering all processes from extraction of wood and other raw materials, transport of these materials to processing locations, all manufacturing steps, delivery of all components and installation at the V&A in London.

RENEWABLE MATERIAL

Tulipwood, which makes up nearly 98% of the mass of *Multiply*, is one of the most abundant American hardwoods with forest volume of over 1000 million m^3, 7% of the total U.S. hardwood resource.

Tulipwood is under-utilised from a forestry perspective. The creation of larger markets for this timber would reduce pressure on other less abundant commercial hardwood species and enhance financial returns from sustainable management of diverse semi-natural forests.

It takes 5 minutes for the 320 cubic metres of tulipwood to be placed by new growth in the U.S. hardwood forest.

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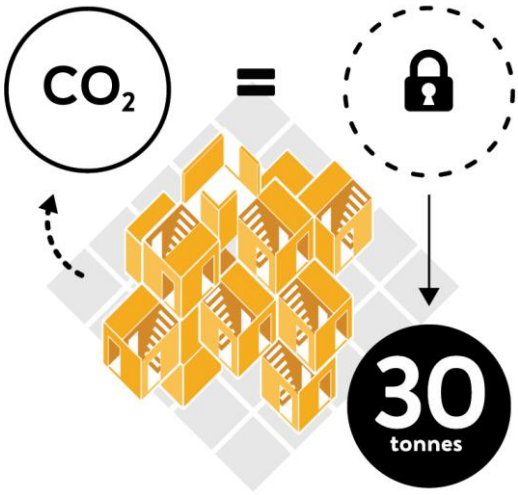
The volume of tulipwood standing in U.S. hardwood forests expands by 19 million m^3 every year. It takes only 5 minutes for the 320 cubic meters of tulipwood logs harvested to manufacture *MultiPly* to be replaced by new growth in the U.S. forest.

CARBON FOOTPRINT

MultiPly is carbon neutral. Carbon emissions of 68 metric tonnes (MT) CO_2 eq. are offset by 38 MT CO_2 eq. due to burning of wood offcuts produced during manufacturing (which substitute for fossil fuel) and 30 MT CO_2 eq. of carbon stored in the wood in the finished installation.



The structure stores a total of 30 tonnes of carbon dioxide (CO_2).

41% of carbon emissions occurred during transport of tulipwood from harvest region and between the various processing stages in the U.S. to point of delivery at Glenalmond Timber in Scotland. Another 30% occurred during tulipwood forestry, kilning and sawmilling operations in the U.S.

Total emissions of 48 MT CO_2 eq. incurred to deliver to Glenalmond the 160 m^3 of rough sawn tulipwood used to manufacture *MultiPly* were more than offset by the 110 MT CO_2 eq. stored in the timber at this stage of the life cycle.

8% of carbon emissions were due to energy use during processing stages in the UK to convert raw tulipwood into finished panels and install in *MultiPly*. During these stages, around 70% of the tulipwood became process waste while 30% was installed in the finished structure. Most of the process waste was incinerated, delivering an estimated 700 GJ of energy for other industrial processes.

Although the quantity of non-wood materials in *MultiPly* is small relative to wood, their contribution to total carbon emissions is significant. Non-wood components, principally

steel fixings with a small quantity of glues and coatings together making up less than 3% of the mass of *MultiPly*, contributed 8.9 MT CO_2 eq. (13%) of carbon emissions.

ACIDIFICATION POTENTIAL

The acidification potential of *MultiPly* is 371 kg of SO_2 (sulphur dioxide) equivalent. Acidification is caused mainly by the burning of fossil fuels and the scale of impact is directly related to their sulphur content.

57% of acidifying emissions occurred during shipping of tulipwood from the U.S. to the UK. Most oceangoing vessels currently burn residual fuel oil with a high sulphur content. This LCA assumes 2.7% average sulphur content for the fuel used on the ships transporting the wood from the U.S. The acidifying emissions of shipping tulipwood may be significantly less with on-going implementation of the International Maritime Organization's target to limit the sulphur content of marine bunker fuel to only 0.5% from 1st January 2020.

17% of acidifying emissions occurred during hardwood processing in the U.S. Some emissions are due to biomass combustion to provide the thermal energy for kiln drying. However, most is due to use of grid electricity to power sawmills and fans during kilning. Two thirds of energy for electricity generation in the U.S. derives from fossil fuel, half of which is coal which has a higher sulphur content than natural gas.

8% of acidifying emissions is due to steel fixings and 5% due to transport of components within the UK.

EUTROPHICATION POTENTIAL

The eutrophication potential of *MultiPly* is 57 kg of phosphate equivalent – about the same as that caused each year by conventional farming of three hectares of land for wheat in the UK. Perhaps surprisingly, hardly any of the eutrophication associated with *MultiPly* is linked to the growth of U.S. hardwood. Fertilisers are very rarely needed to encourage growth of American hardwoods since they thrive under natural conditions. Instead, nearly all eutrophication potential of *MultiPly* is due to nitrate emissions during burning of fuels for transport and processing of materials.

PHOTOCHEMICAL OZONE CREATION POTENTIAL (POCP)

MultiPly has a POCP of 139 kg of ethene equivalent. Nearly all the POCP is attributed to the hardwood processing stage in the US and is due to emissions of terpenes, volatile organic compounds (VOCs) released from wood resins. Terpenes are released naturally as trees grow, but processes in which wood is heated (such as a kiln drying) result in more significant emissions.

Most U.S. hardwood processing happens in rural areas with the implication that terpene emissions are less likely to contribute to urban smog. For the public, the smell around wood-processing units is likely to be the most noticeable environmental effect. Nevertheless, the photo-oxidants created due to terpene emissions can cause forest and crop damage, and they are harmful to humans as they cause irritation in the respiratory tract and in sensitive parts of the lungs.

PRIMARY ENERGY DEMAND

1004 GJ of non-renewable (fossil fuel) energy was used to create *MultiPly*, 68% to supply the wood, 6% to supply steel fixings, 10% to supply glues and coatings, 8% during manufacturing and installation in the UK, and 8% for transport of components in the UK. Incineration of process waste at various stages offset demand for non-renewable energy by 680 GJ.

2510 GJ of renewable energy was used for *MultiPly*. Burning of process waste offset demand for renewable energy by 30 GJ.

90% of renewable energy input is at the forestry stage. This is not energy used during forestry operations but consists of solar energy absorbed by the tree during growth and converted into chemical energy within the wood itself. It is equivalent to the energy that would be released if the wood were burnt immediately after harvest and is recorded in the LCA to ensure full accounting of energy streams.

Much of the remaining renewable energy is used during the wood processing stages and is indicative of the high dependence on biomass to produce thermal energy during kiln drying. At least 90% of all thermal energy used for kiln drying in the U.S. hardwood sector is derived from biomass.

FUTURE USE AND LEGACY

MultiPly demonstrates the technical and environmental potential of a new construction product - hardwood CLT. This potential, and the message *MultiPly* sends out, may be more relevant than the immediate - and more readily quantifiable - environmental impact of *MultiPly* at the times and places it is on display.

The immediate environmental impact of a demonstration project, which by their nature involve experimentation and some trial and error, also tends to be high relative to more highly evolved commercial operations. Therefore, the fact that *MultiPly* is carbon neutral, despite these challenges, seems more significant and is a tribute to the inherent environmental strengths of tulipwood CLT.

Equally significant is that *MultiPly* is fully demountable and can be flat-packed into its component kit of parts and put back together in several different configurations. Long

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life in use significantly mitigates the environmental effects of the design. Less regular replacement means less repetition of impacts. Long-lived wood products also supplement the carbon store in the forest and help to keep CO_2 out of the atmosphere.

The use of tulipwood, largely untarnished by mixing with other materials and chemicals, ensures that at the end of *MultiPly*'s life, the panels are readily reusable and recyclable and any components needing to be disposed of are biodegradable and non-toxic. They may also be safely incinerated, providing a carbon-neutral source of energy.

REFERENCES

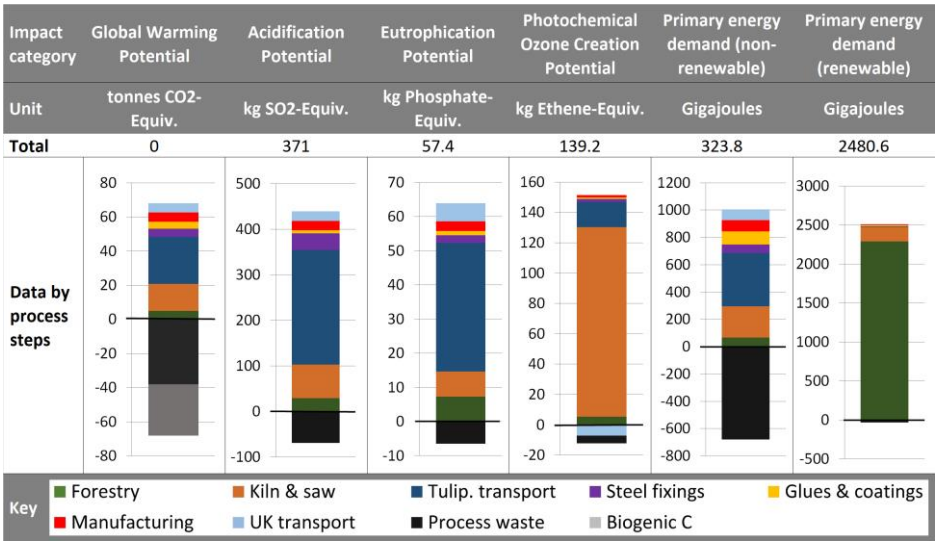

Chart 1: *MultiPly* environmental effects by impact category and process stages

Impact Category	Unit	American tulipwood			Steel fixings	Glues & coatings	UK manu-facturing	UK transport	Process waste	Stored carbon	Total
		Forestry	Proc-essing	Transport							
Global Warming Potential	MT CO2-Equiv.	4.8	15.9	27.6	4.7	4.1	5.4	5.4	-38.0	-30.0	-0.1
Acidification Potential	kg SO2-Equiv.	29.1	73.8	251.9	36.2	6.7	20.4	21.5	-69.0	n/a	370.7
Eutrophication Potential	kg Phosphate-Eq.	7.3	7.3	37.7	2.2	1.3	2.9	5.2	-6.5	n/a	57.4
POCP	kg Ethene-Equiv.	5.3	125.0	16.5	2.1	1.0	1.6	-7.1	-5.1	n/a	139.2
PED (Non-Renewable)	Gigajoules	65.6	231.2	388.6	63.1	95.2	81.4	79.0	-680.3	n/a	323.8
PED (Renewable)	Gigajoules	2287.1	183.3	6.2	5.1	14.9	9.8	4.2	-30.0	n/a	2480.6

Table 1: *MultiPly* environmental effects by impact category and process stages

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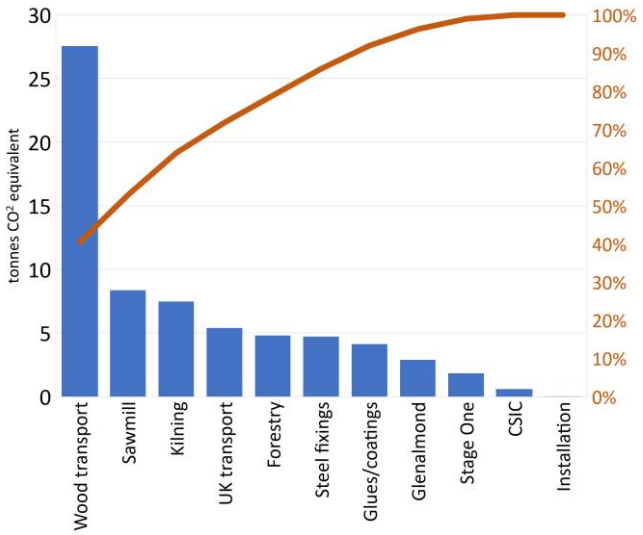
	Unit	Amount
Kiln dried sawn tulipwood delivered from to Glenalmond Timber from U.S.		
Quantity	Cubic meters	160.7
	Metric tonnes (MT)	77.9
Replacement time	Seconds	312.0
Outputs from UK manufacturing sites		
Installed in Multiply	Metric tonnes (MT)	20.8
Incinerated	Metric tonnes (MT)	55.0
Reused	Metric tonnes (MT)	0.5
Sawdust emitted/landfill	Metric tonnes (MT)	1.6
Energy generated	Gigajoules (GJ)	710.3

Table 2: *MultiPly* tulipwood material balance

Process	MT CO2-Eq.	%
Emissions		
Tulipwood	48.3	71%
Forestry	*4.8*	*7%*
Processing	*15.9*	*23%*
Transport	*27.6*	*41%*
Steel fixings	4.7	7%
Glues & coatings	4.1	6%
Manufacturing	5.4	8%
Transport to site	5.4	8%
Total emissions	**68.0**	**100%**
Offsets		
Process waste offset	-38.0	56%
Biogenic carbon	-30.0	44%
Total offsets	**-68.0**	**100%**
Total carbon footprint	**-0.1**	

Table 3: *MultiPly* carbon emissions and offsets by process stages



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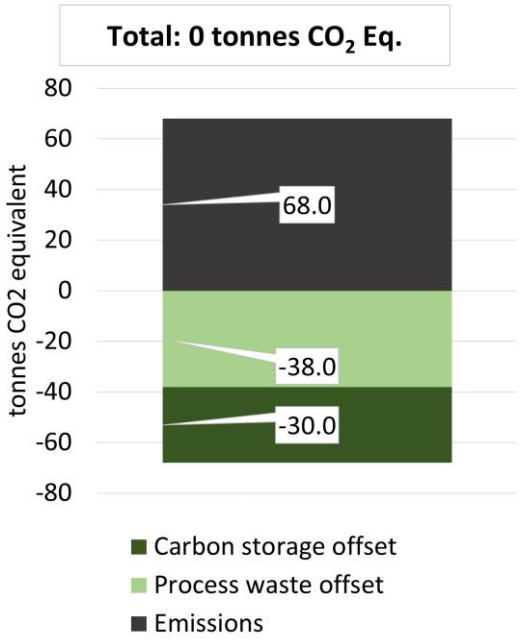

Chart 3: *MultiPly* summary of carbon footprint.