TECHNICAL NOTE: A PRELIMINARY STUDY TO QUANTIFY THE ENVIRONMENTAL IMPACTS OF CONCRETE AND CORK FLOORING

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Abstract. Cross-laminated timber (CLT) is currently sought as a sustainable and green building material. It does not meet the International Building Code sound insulating requirements, and either a concrete slab or hardwood flooring is needed to meet the acoustic and vibrational performance benchmark. Cork, the bark of the cork oak, is well known for its sound insulating properties and often used for flooring applications in Europe. The cork-based flooring system is a potential solution to the acoustic problem faced by the CLT building industry. The goal of this preliminary study was to quantify the environmental impacts of a concrete and a cork-based flooring system that includes CLT. A life-cycle analysis (LCA) is conducted to focus on a cradle-to-gate comparison of a cork flooring system with a locally sourced concrete flooring system for use in a proposed CLT structure in Portland, OR. The LCA reveals that the global warming potential (GWP) of concrete is 25% higher for the concrete flooring system. For cork flooring, the GWP is mainly driven by inorganic compounds in the flooring assembly. The main source for cork is Portugal, which increases the GWP of the cork flooring system, in contrast to that of concrete flooring, which typically has a regional production and supply system. As environmental abatement costs increase, the profitability of cork flooring can increase to justify the creation of an appropriate system to close the loop.

Keywords: LCA, sustainable, renewable, flooring, cork, cement, CLT.

INTRODUCTION

The development and application of sustainable products for the construction of our built environment is the first step toward minimizing the environmental impact and stewardship of our natural resources. Present-day innovations in the use of unique green products have opened the doors to new methods in how we approach construction. Of these products, cork flooring exemplifies the definition of a "sustainable product."

Cork is the outer bark harvested exclusively from cork oak tree, *Quercus suber* L., found predominantly in the Mediterranean region. The bark is a vegetal tissue composed of an agglomeration

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of cells filled with a gaseous mixture similar to air and lined with alternating layers of cellulose and suberin. Approximately 89% of the tissue of the bark consists of gaseous matter, making the specific gravity of cork extremely low (0.12-0.20). The result is a large disproportion between the volume and the weight of the material. Cork production has shown significant expansion in recent years, reflecting the impact of approximately 120,000 hectares of highly productive new cork forests in Spain and Portugal (Cork Oak Forest Area 2010). Cork's elasticity, combined with its near-impermeability, makes it the perfect material for making bottle stoppers, floor tiles, insulation sheets, bulletin boards, and other similar products. Cork used in wine bottle stoppers accounts for approximately 15% of total production by weight, yet it captures two-thirds of the revenue (greater than 1 billion euro). Cork flooring, insulation, and underlayment for the construction industry make up the rest of the cork revenue (Cork Oak Forest Area 2010). Cork flooring is a composite of the by-product from the production of cork bottle stoppers used primarily in the wine industry (Mestre and Vogtlander 2013).

Cork flooring is a natural soundproofing material. The product also does not use any resin, which makes it an ideal choice for green construction. Currently cork is grown and harvested mainly in Portugal and Spain (APCOR 2016) and that is one factor that adds to its environmental impacts, particularly due to transportation needs. The delivery of this product to the US markets, specifically in the Pacific Northwest, would need a complex supply chain requiring ocean freighters and cross-country transport. With this dilemma in mind, the question is posed, "Does cork create less of an impact than other existing solutions to meet acoustic requirements?"

Another product that is being projected as a green material and has gained more attraction as it enables tall mass timber buildings is cross-laminated timber (CLT). CLT is an engineered wood product that can be used as an alternative to traditional structural building materials such as steel, concrete, or masonry. CLT typically consists of three, five, seven, or nine layers of dimensional lumber with adjacent layers perpendicular to one another. Whereas CLT has been accepted and integrated into the European construction market, interest has been rapidly growing in the United States, New Zealand, Australia, Japan, Chile, etc. (Lehmann 2012). A study of two mid-rise office buildings showed that compared with concrete, CLT exhibited a more positive environmental performance in all impact categories, including ozone depletion, global warming potential (GWP), and eutrophication (John et al 2009). A survey conducted in 2014 showed that CLT's environmental performance was a significant factor for US architects' consideration in material specification, as 85.2% of respondents noted this criterion as "very important" or "important" (Mallo and Espinoza 2015). A recent study comparing CLT-based construction with that involving concrete in China showed a 30% lower energy consumption during the use phase for CLT buildings in Xi'an and Harbin (Liu et al 2016).

There are, however, some concerns regarding CLT's acoustic performance. Furthermore, acoustic performance is significant in the adoption of mass timber construction as half of prior respondents ranked this criterion as "very important" or "important" for material selection (Mallo and Espinoza 2015). In a follow-up survey distributed to several European stakeholders involved in CLT research and construction, including researchers, engineers, educators, consultants, and architects, almost half (45.1%) of all respondents indicated "acoustic performance" as medium or high priority for further research (Espinoza et al 2016).

The International Building Code (IBC) specifies two types of laboratory sound tests relating to acoustic performance: impact insulation class (IIC) and sound transmission class (STC). IIC tests the resistance of a material in sound transmission via structure-borne noise, for example, high heels walking across a floor or objects dropped directly on the floor. STC is a measure of a construction assembly's ability to reduce airborne sounds, including voices, music, television, and other ambient noises (NALFA 2012). In a Canadian study, FPInnovations reports that a standard five-layer CLT structure without any additional materials has both an IIC and an STC rating of 45, whereas the minimum requirements as stipulated in the IBC is 50 for both (Karacebeyli and Douglas 2013). There are two ways to increase the IIC and STC rating. One is the use of a concrete slab on top of the CLT panel and the other is the use of a hardwood flooring system along with the CLT panel. The schematics of two flooring systems are presented in Fig 1. The concrete-based system is composed of an underlayment, placed between the CLT and the concrete flooring surface. The cork flooring–based system is similarly composed with an underlayment separating the cork flooring from the CLT. The major difference between the two systems is the sound-insulation and gypsum board layers on the underside of the CLT panel.

The goal of the study was to quantify the environmental impacts of two flooring systems, which are potential solutions to mitigate acoustic concerns of the CLT flooring system. A life-cycle analysis is conducted to focus on a cradle-to-gate comparison of a cork flooring system and a concrete flooring system for use in a proposed CLT structure.

METHODS

Goals and Scope

This LCA focused on a cradle-to-gate comparison of a cork flooring system and a locally sourced concrete flooring system for use in a proposed CLT structure in Portland, OR. The analysis will factor in the inputs and outputs from each stage of the life cycle of the product from the extraction or sourcing of raw materials, transportation, manufacturing of the products, to finally transporting to the job site, following the guidelines within ISO 14044 (Normalización Organización Internacional de 2006). An overview of relevant stages, inputs, and outputs is given in Fig 2. All modeling was performed in GaBi (Thinkstep Global 2017). The impacts of

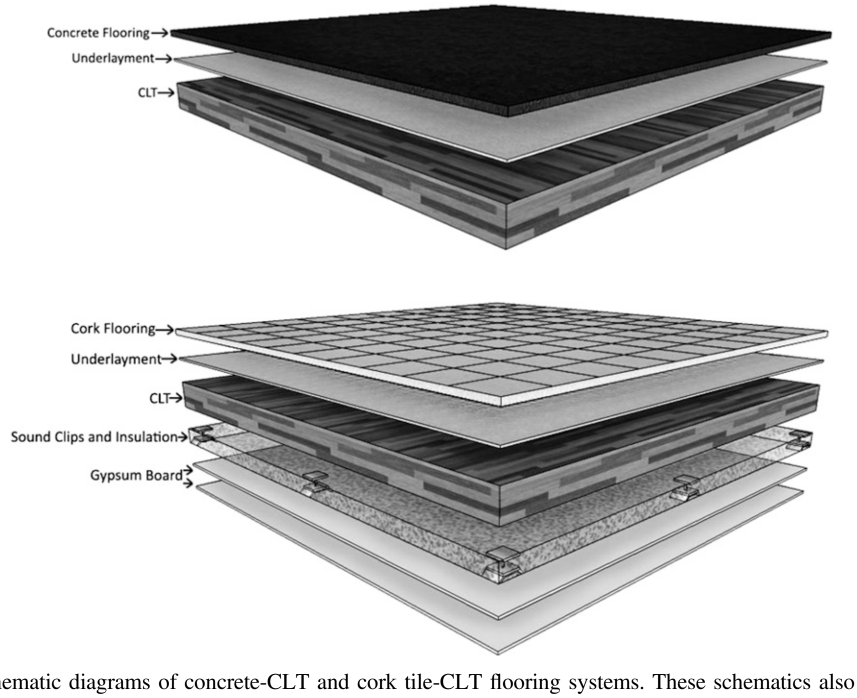

Figure 1. Schematic diagrams of concrete-CLT and cork tile-CLT flooring systems. These schematics also represent the respective functional units.

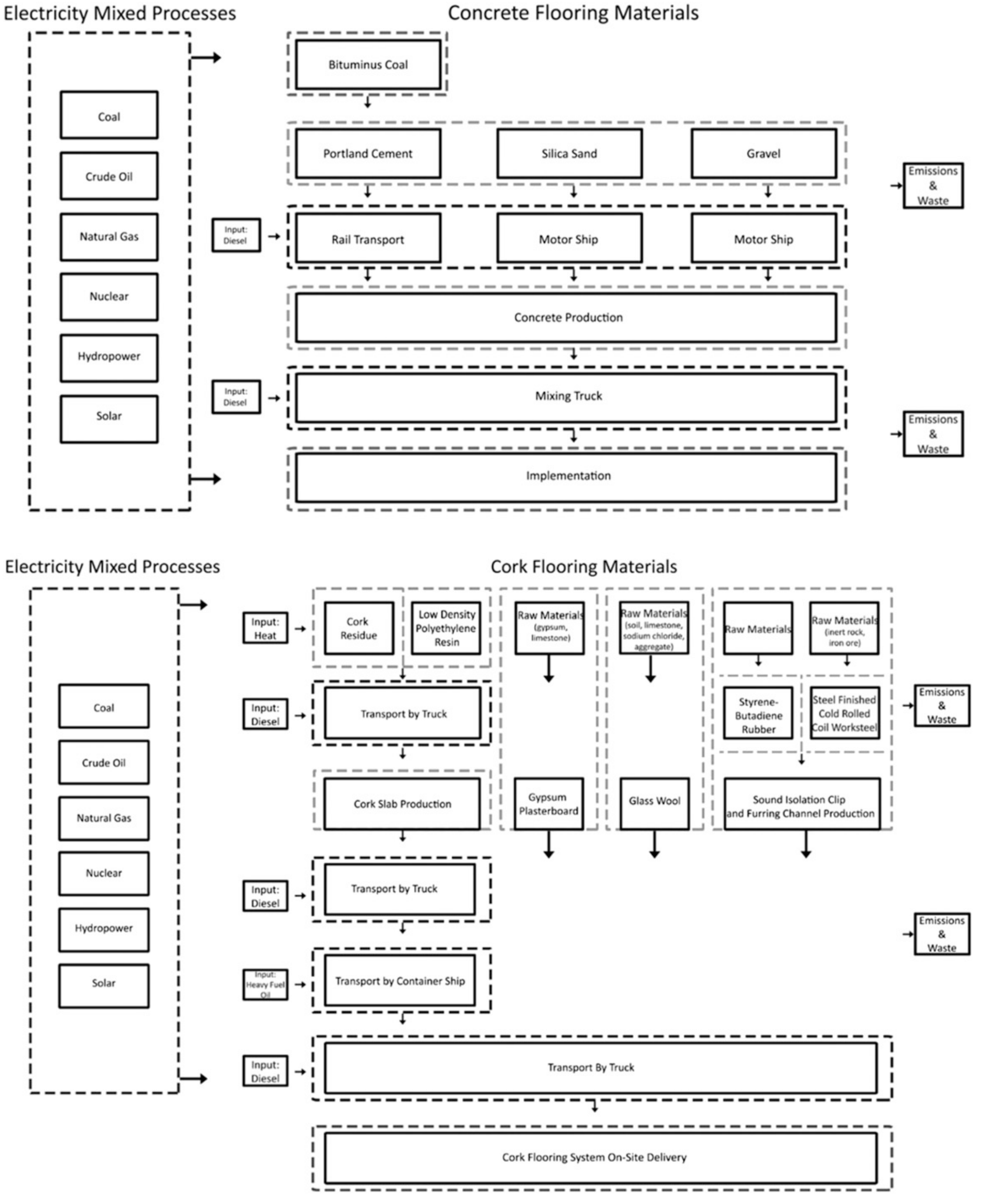

Figure 2. Systems for concrete and cork flooring, production flow, energy inputs, and emissions.

the installation of the materials, postconstruction, deconstruction, and recycling or disposal were not included in the system boundary for this LCA study.

Functional Unit

The functional unit for these analyses, as shown in Fig 1, maintains two equivalencies. First, the physical footprint of both systems is 11 m^2 (roughly 100 square feet) and, second, both floor systems meet an IIC and STC rating of 50 for acoustic performance. To achieve this minimum benchmark performance, the cork flooring system uses cork flooring tiles on the surface. It is installed over an underlayment placed between the flooring tiles and the five-layer CLT panel. Next, sound clips and furring channels are fixed to the panel's undersurface. Sound absorption material such as fiberglass insulation is lodged between the furring channels and two layers of gypsum board are suspended from the sound clips. A schematic of the cork flooring system is shown in Fig 1b. The concrete flooring system has an underlayment on top of the CLT panel and then a 38-mm concrete topping. Woodworks specified an underlayment such as a rubber mat, texture felt, or low density wood fiberboard (WoodWorks). However, because the underlayment was similar in both flooring solutions, it was not included in the comparative LCA. It must be noted that contrary to Woodworks' recommendation on underlayment, feedback from industry professionals has indicated that underlayment is not always used in concrete flooring applications. Both these flooring systems are installed on an identical five-layer CLT panel, which is excluded from the comparative assessment.

Life-cycle Inventory

Cork – raw material sourcing. Cork trees are harvested manually. There is currently no mechanized harvesting system available, nor does the market seem to demand such mechanization. Diligence and vigilant attention are required while performing this operation as the quality of cork and integrity of the tree depend on this operation. Extraction operations occur during midsummer, when the bark begins to separate from the living tissue of the tree. Extractors split the bark and strip off the bark without reaching the living tree. The stripped planks are stacked for 6 mo outside for conditioning. Subsequently, they are steamed in boilers to eliminate insects and contaminants, and then the outside layer of the bark is removed. This also increases the cork's flexibility. Finally, they are stored for three weeks before being punched into bottle stoppers for the wine industry. Cork flooring is actually made from the residues of cork stopper production, which are essentially by-products in terms of LCA. Other products such as cork boards, coasters, and fashion accessories are also made with the remaining material, ensuring zero waste.

Cork flooring production. Cork flooring tiles are made by crushing down the by-product of cork stoppers and compressing it into a solid sheet. No resin is needed for this and the only input into creating a solid sheet is heat using steam. The sheet of cork is then finished with a polyurethane or ceramic bead coat to seal and create aesthetic appeal for custom applications. A thin sheet of cork backing is applied to the surface to create more sound reduction, and notches are etched on the sides to create a lock-in structure for the cork panels. Similar to laminate flooring, no adhesive is required to place the flooring. The cork flooring is then packed for shipping.

Transportation of cork flooring. The site chosen for this study was Portland, OR. This provides a realistic scenario for analyzing the impact and sourcing of building materials to the Pacific Northwest.

Cork. The production site is in the city of Oleiros, Portugal. Flooring tiles are transported 211 km to Porto, Portugal, by truck to be shipped to Seattle, WA, by boat. The shipment takes approximately 25 d and covers a distance of 15,425 km, traveling at an average speed of 14 knots or 29.6 km/h. From Seattle, the cork flooring tiles are hauled to Portland in a truck.

Fiberglass. Owens Corning R-13 fiberglass insulation was chosen because of its common availability and thickness of 3.5 inches which allows it to fit in the four-inch cavity between the CLT panel and gypsum board. Specifications for area and weight were taken off the manufacturer's specifications and normalized for our functional unit. Materials were assumed to be manufactured in the company's facility in Santa Clara, CA, and shipped 1070 km via truck to the jobsite.

Insulation. Rock wool has a great impact compared with other insulations, so it was also selected in an effort to create an unbiased material selection to help provide a fair comparison of the two flooring systems.

The sound isolation system consisted of sound isolation clips and furring channels to mount the gypsum off board that forms a cavity, which is filled with insulation. Normalization of our functional unit followed the guidelines provided by documentation for Pliteq's Genie Clips and ClarkDietrich's Environmental Product Declaration for cold-formed steel products (Pliteq Inc. 2008; ClarkDietrich 2015). The material composition of Pliteq's sound isolation clips was assumed to consist of 80% steel and 20% rubber, modeled in GaBi by the steel-finished cold-rolled coil and styrene–butadiene rubber (SBR) mix, respectively. A custom process was then created in GaBi, based on existing processes including steel sheet stamping and bending as well as other metal manufacturing processes. Whereas Pliteq is based in Toronto, Canada, the closest manufacturing facility for ClarkDietrich was in Woodland, CA. It was assumed that both sound isolation clips and furring channels would typically be sourced from the same manufacturer. Thus, both materials were shipped 906 km by truck from ClarkDietrich's facility to Portland, OR.

It is also important to note that although several processes actually occurred in the United States, the relevant processes in the databases only allowed for global specification (for example for the manufacturing of the cold-rolled steel coils) and German production (for example SBR). Similarly, gypsum board would realistically be produced in the United States; the available process for gypsum plasterboard manufacturing in GaBi's database was modeled after facilities in the European Union. As the processes are same and technological advancements in these regions are similar, differences are negligible for the objective of this assessment.

Assembly. Finally, data required to complete the cork flooring system were gathered from National Gypsum for the final element—two layers of 1.58 cm gypsum board (National Gypsum 2000). The company's closest sheetrock manufacturing facility was in Richmond, CA, 1003 km from the jobsite in Portland.

Concrete flooring system. The concrete mix modeled in our study was selected based on prior work by Sophia Hsu and mix proportions were confirmed by the Portland Cement Association (Nisbet et al 2002; Hsu 2010). FPInnovations specified a unit weight of 76. kg/m^2 (Karacebeyli and Douglas 2013).

Knife River is one of the leading producers of aggregates in the United States, and primary communication with their Portland dispatch office regarding their supply chain provided information and data for our model. This study assumes that the cement is produced by Ash Grove in Durkee, OR, and then transported by rail 544 km, to Knife River's Ready Mix facility in Portland where materials are localized, mixed, and loaded into mixer trucks for dispatch to the final jobsite. Likewise, Knife River indicated that both fine and coarse aggregates would be sourced from their quarry in Deer Island, OR, and shipped to their facility by barge. Both silica sand and 2/3 gravel *cradle-to-production gate* processes were selected in GaBi for this analysis, and a transport distance of 32.2 km was assumed.

RESULTS AND DISCUSSION

Life-cycle Impact

A comparison of the GWP for both flooring systems is presented in Fig 3. The cradle-to-gate environmental performance of the two flooring systems is different. The cork system has 25% less GWP than the concrete system. An 11 m^2 section of concrete flooring resulted in 785 kg of CO_2-equivalent air emissions, whereas emissions from the cork flooring system were roughly 25% lower at 574 kg.

TRACI (Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts) was used, as it is adapted for the US market. It allows quantification of potential impacts from inputs and releases in a set of impact categories (Bare 2011). Manufacturing processes related to the cork production were extracted from the EcoInvent Database in SimaPro and adapted for use in GaBi; likewise, GWP impact from SimaPro was measured using the TRACI protocol. Another assumption previously mentioned is that not all processes shown in GaBi were set to their realistic manufacturing location, yet any differences were assumed to be negligible and so modeling congruent process flows was assumed to result in accurate results for the objective of this assessment.

Concrete Flooring System

GWP impacts associated with concrete production expressed in kg CO_2 equivalents are

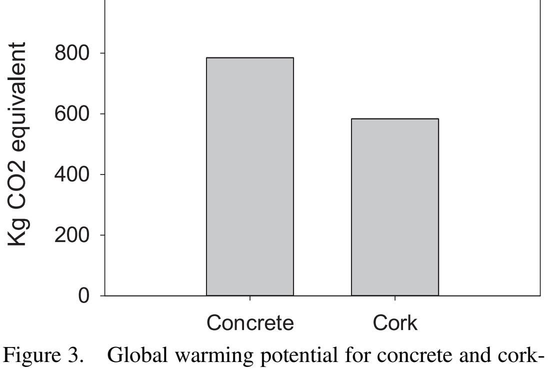

Figure 3. Global warming potential for concrete and cork-based flooring systems in kg CO_2-equivalent emissions.

listed in Table 1 along with their percent contribution to the total impact of the process. The currently required process to source and produce concrete leaves little room for improvement to create a more sustainable product. The production of Portland cement and concrete make up 77.1% of the overall CO_2-equivalent air emissions. The raw materials are nonrenewable and energy intensive to collect and combine. One aspect that could contribute to a more sustainable strategy in concrete flooring systems is the use of fly-ash and the use of recycled concrete and coarse aggregate. The downside to this recycling technique is that repurposing deconstructed concrete is not widely used for typical flooring applications, and while not included in the scope of this study, it may be more energy intensive and detract from the objectives for sustainability. As little as 1.5% of CO_2-equivalent air emissions are caused by transportation.

Cork Flooring System

The highest impact for the cork flooring system is from the steam-generated heat required (Table 2) to cure the resin that bonds the compressed cork particles in the creation of cork flooring slabs. The heat contributes 31% of the total impacts of the product. As this is a necessary aspect to the process, a suggestion to decrease the impact of this flooring system would be the use of a thermosetting adhesive. The second highest contributor to the cork flooring system was the use of fiberglass insulation necessary to achieve the STC rating of ~50 as specified by WoodWorks (2017). Glass wool insulation contributed 21% of the carbon footprint for cork (Table 2). The insulation chosen in this study carries the highest impact out of all available alternatives (Pargana 2012). Any alternative insulation could lower the impacts further. Some cork flooring manufacturers integrate insulating materials which are purported to negate the necessity for additional sound dampening systems (insulation, gypsum board, and the sound isolation clips and furring channels to secure and suspend the material). The use of tiles with integrated insulation could

Table 1. Impacts associated with all the steps in concrete production for an 11 m^2 concrete-CLT flooring system. All calculations are based on C30/37 ready-mix process.

Process	Region	Database	kg CO_2-equiv.	%
Portland cement, at plant	US	USLCI	305.92	39.0
Concrete production	DE	Thinkstep	299.44	38.1
Bituminous coal, combusted in industrial boiler	US	USLCI	93.43	11.9
Silica sand (excavation and processing)	DE	Thinkstep	44.17	5.6
Electricity grid	US	Electricity grid mix	23.56	3.0
Rail transport cargo – diesel	GLO	Thinkstep	3.95	0.5
Gravel 2/32	EU-27	Thinkstep	3.64	0.5
Natural gas, combusted in industrial boiler	US	USLCI	3.60	0.5
Truck	GLO	Thinkstep	3.17	0.4
Motor ship	GLO	Thinkstep	2.54	0.3
Diesel mix at refinery	EU-27	Thinkstep	1.68	0.2
Total kg CO_2-equivalent air emissions			785.1	

substantially lower the environmental impact by an estimated 15%, as sound isolation system and gypsum board are removed from the life-cycle inventory. Even if this integration were not pursued, the use of alternative insulation materials alone would render a significant reduction to the cork flooring system.

As cork is produced in a specific region of the world and then shipped to the United States, it is expected that transportation will have a higher contribution toward its GWP (Table 2). Cork flooring requires a finish coating made out of polyurethane. The results in Table 2 suggest that the polyurethane finish did not create a large impact. Polyurethane could still have a long-term effect on the environment, so other finishes could be investigated into as an alternative, possibly lowering the overall impact.

It takes innovation and time to increase the sustainability and decrease the carbon footprint of every component in a composite structure. Closing the loop for the production, utilization, and recycling of cork could make it an ideal resource for various green building materials. Eventually, economic aspects are often the main drivers in the decision process. As the cost to mitigate ecological impacts increases and the infrastructure for more sustainable products improves, the landscape of building products will significantly change.

Table 2. Impacts associated with all the steps involved in an 11 m^2 cork-CLT flooring system.

Process	Region	Database	kg CO_2-equiv.	%
Heat	EU-27	Thinkstep	180.8	31.0
Glass wool	EU-27	Thinkstep	122.5	21.0
Cork flooring production	PT	EcoInvent	78.6	13.5
Container ship	GLO	Thinkstep	76.8	13.2
Steel-finished cold-rolled coil	GLO	Worldsteel	61.0	10.5
Truck/Truck-trailer	GLO	Thinkstep	27.2	4.7
Gypsum plasterboard	EU-27	ELCD/EUROGYPSUM	20.0	3.4
Heavy fuel oil at refinery	EU-27	Thinkstep	8.5	1.5
Electricity grid mix	US	Electricity grid mix	3.5	0.6
Diesel mix at refinery	EU-27	Thinkstep	3.4	0.6
Sound isolation clip and furring channel production	GLO	Thinkstep	0.7	0.1
Low density polyethylene resin, at plant	RNA	USLCI	0.6	0.1
Styrene–butadiene rubber (SBR) mix	DE	Thinkstep	0.4	0.1
Cork flooring system, on-site delivery	US	n/a	0.0	0.0
Cork residue	US	n/a	0.0	0.0
Total kg CO_2-equivalent air emissions			584.0	

CONCLUSIONS

When comparing a natural resource such as cork with concrete within a floor system, the cork-CLT flooring exhibited a lower GWP than its concrete-CLT counterpart did. The impacts associated with the cork-CLT flooring system were 25% lower than those of the concrete flooring system. As cork moves along the chains of production and commerce, the environmental impact increases. Cork is manufactured in only one part of the world and, hence, transportation contributes significantly to the total impacts of the cork-CLT flooring system. To manufacture a high-performing and durable cork flooring product, additional materials and processing are required that significantly impact the environmental performance of cork. As shown through this LCA, insulation materials, production, and transportation have a significant impact on emissions.

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